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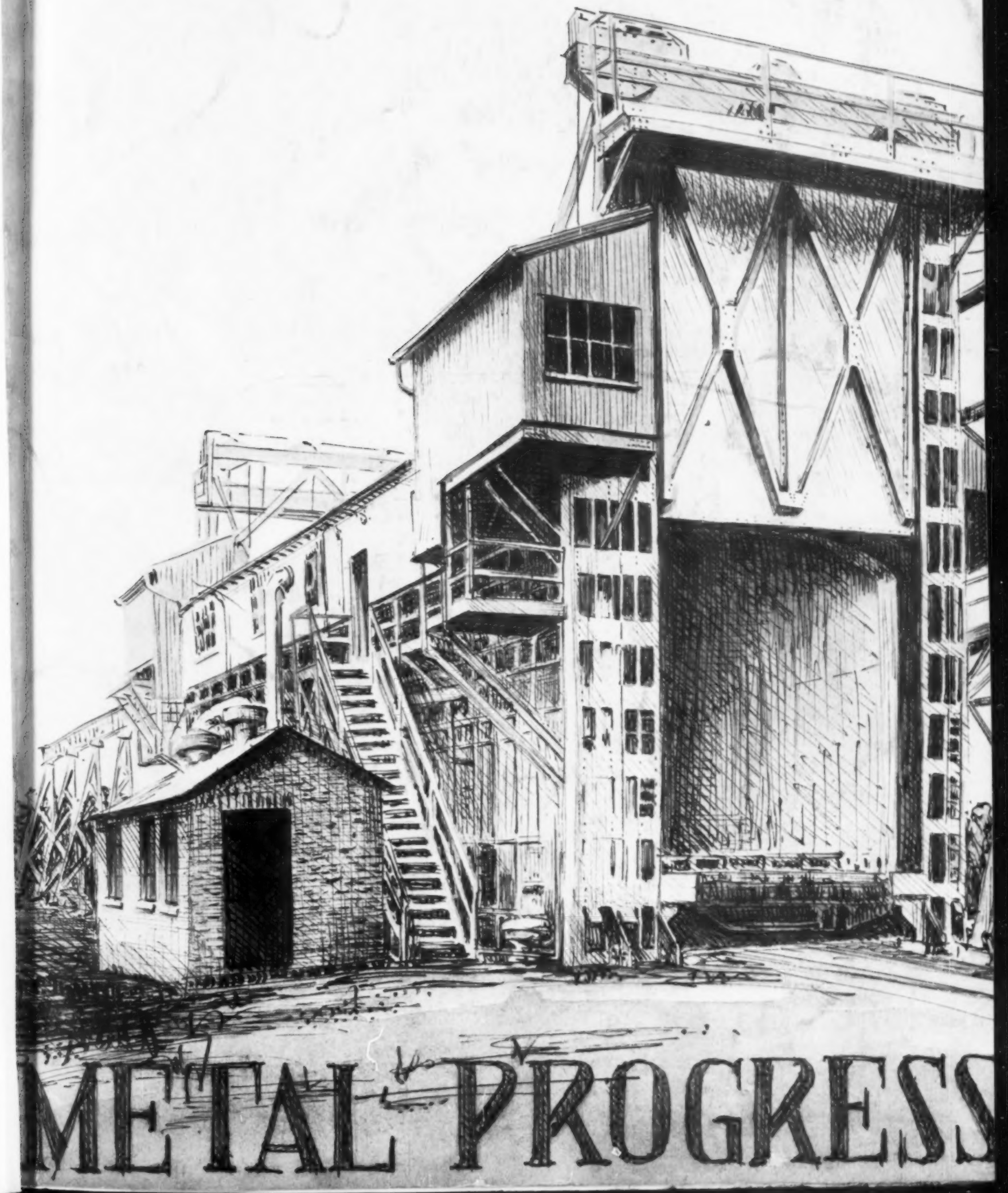

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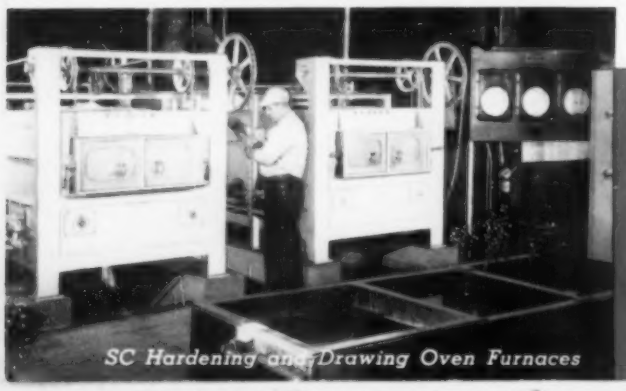

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METAL PROGRESS

JULY, 1939 VOLUME 36, NO. 1

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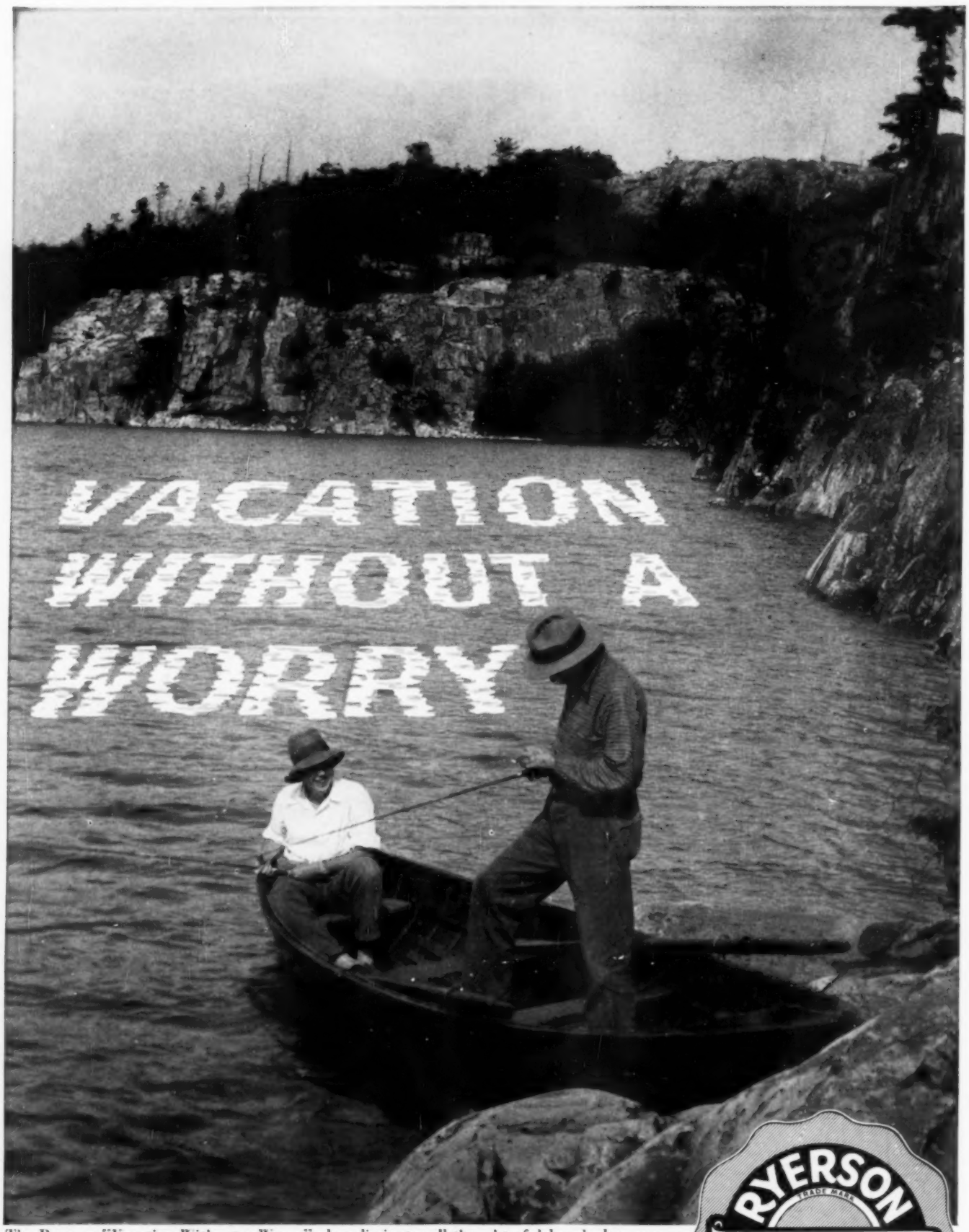

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METAL PROGRESS

VOL. 36 JULY, 1939 NO. 1

CRITICAL POINTS

By the Editor

IN A SHORT TIME at Bell Telephone Laboratories, in New York City, was dizzied by many remarkable things shown by EARLE SCHUMACHER, research metallurgist. Of the number, perhaps a 20-roll mill will be of widest interest. This is a small cluster mill with tension take-ups and hold-backs for cold rolling thin strip up to 2 in. wide. Work rolls are driven, but absorb only a small per cent of the power; they may be 0.30 to 0.15 in. diameter, depending on the thinness of strip being rolled, the smallest resembling an oversized knitting needle. Top and bottom work rolls are each backed up with two idling rolls, these in turn by three more, and the hold-down pressures imparted by a final cluster of four "large" rolls about 1½ in. diameter, running in needle bearings. To correct for spring in the assembly, the work rolls are crowned ever so slightly to a circular arc rising 1.6 mills in a 3-in. span — a matter requiring utmost accuracy, as indeed do all parts of this mill and its drive. It can make a 90% reduction in copper in one pass and 50% in steel just as easily. CHARLES WAHL, who looks after this instrument of high precision in the Bell Laboratory, had samples of gossamer-thin metals of many sorts ranging from duralumin through stainless steel to permalloy. Work on soft metals may start on thicknesses of 0.035; copper has ended at a little thicker than 0.0001 in. (which may be compared with 0.00008 in. for beaten gold leaf). The thickness is quite uniform even though the surface is slightly wrinkled.

Cold rolling without annealing

The amazing thing is that rolling need not be interrupted for annealing. For instance, steel strip 0.005 in. thick can be rolled once to 0.002 in., again to 0.001, and next to 0.0007 — a total reduction of 96% in three passes. What are the theoretical reasons for the ability to keep on rolling cold strip without intermediate heat treatments? The secret of the enormous reductions in a single pass lies in the small diameter of the work rolls, which are proportioned to the thickness of the strip so as to obtain a large angle of pinch.

OUT TO Baltimore's pleasant suburb of Catonsville, where EMIL GATHMANN, past national treasurer ⛑, has parked his business connected with better ingot molds for sounder steel. ("Parked" is the correct word to describe the surroundings.) We talked about how easy it sometimes is to blow a fanfare about a novel technique or process, and how silent the press may be when the revolutionary idea later fails to revolutionize the industry. He cited copper stools for ingot molds, greatly touted and expensively purchased not so long ago, but now mostly forgotten — except for tool steels.

Direct rolling not yet commercial

GEORGE NAUSS, chief metallurgist of Crown Cork and Seal Co., also told us that the process of rolling strip direct from molten metal, featured in the trade press three years ago and the basis of an article in an English magazine as late as last January, was quickly abandoned due to a variety of difficulties, among them the deterioration of the rolls under molten metal.

Such ready acceptance of new ideas by steel makers is not a part of GATHMANN's remembrances! He said that eight lean years passed before the big-end-up ingot was given a trial on real tonnage. That was in the War when the British were pressing Pittsburgh for 12-in. shell. A small reduction, ingot to round, failed to close up the secondary pipe in the killed steel ingot, and it was so easily seen by inspectors that no more than 25% of the steel

would pass. Molds with heavy bases and bottom walls, casting ingots big-end-up to localize the pipe at the top, tripled this yield of sound metal, and saved the day for Kitchener.

P.S. — Sound ingots with good skin would be easy to cast if conditions in the ladle and mold were *exactly* right; unfortunately this concatenation of circumstances *never* occurs by accident — well, hardly ever.

ATTENDED a meeting of the Metallurgical Advisory Committee at the National Bureau of Standards, where various members of the department under HENRY RAWDON reported on their projects, leaving the general impression that the numerous activities are being well handled by quite competent men. The Advisory Board did very little advising; probably it would be better if the visitors primarily interested in corrosion, fatigue, non-ferrous metals, and so on could gather in smaller groups in the respective laboratories (rather than in a large lecture room) to discuss their specialties.

A new micro-indenter

In such an adjourned meeting, BILL SWANGER told an interested group of us about the new Knoop Indenter for hardness measurement, developed by two men in the optics division: CHAUNCEY PETERS and FREDERICK KNOOP. In principle this is a refined Vickers hardness machine; the diamond indenter instead of being cut to a square based pyramid is a pyramid with a rhombus base, and apex angles so selected that the indentation is a diamond shape about seven times as long as it is wide. The long diagonal is measured under the microscope, it gives sharper end intersections than the short diagonal, less influenced by elastic recovery of the material under test. The load is from 50 g. to 4 kg., adjustable so that the indentation will be about 100 microns long (0.004 in.). Indentations as small as 40 microns are clearly measurable on hard materials. Hardness number is computed from the ratio of load to the area of the impression at the surface of the specimen (the latter being proportional to the indentations' major diagonal).

Small loads and tiny indentations can be used, for instance, to measure the hardness of individual microconstituents, of thin nitrided cases cut normal to the surface, and variation of hardness with direction in crystals. Martensite is 800 hard, nitrided steels 1100, boron carbide (the hardest metallic constituent yet measured) 2300. The various minerals numbered 1 to 9 on Moh's mineralogical scale are found to be properly spaced by a progression of numbers, but there is a great gap between sapphire (No. 9) and diamond (No. 10). The latter has been measured at 8300, on a ground face. Measurement of the indentation in various engine parts, before and after a test run, indicates the wear on such surfaces, almost imperceptible otherwise.

TO DETROIT on the crest of a heat wave, but fortunately in an air conditioned streamliner, to inspect the new Carboloy factory, itself largely air conditioned. In the evening on the cool Detroit River, attempting to view the King and Queen's reception in Windsor from the deck of the commodious motor boat belonging to BILL CALKINS, staff engineer in the Chrysler organization, but getting not much closer than the booming muzzles of the field guns, there to be showered with burnt wadding during the salutes. Returned by sleeper, *not* air conditioned — evidently the railroad's means of competing *(sic)* with the D & C night boats. 'Tis the life of Reilley, the Editor's!

New uses for hard carbides

VAN FISHER has made us some fine photographs of the essential operations in making cemented hard carbides, and we will eventually have a pictorial story from this model factory. Surprising it is that in 10 years hard carbide has grown from a laboratory item to an essential commodity warranting the construction of a million dollar factory — and this company is only one of several American producers. WALTER ROBBINS, Carboloy's president, said that a ten-fold increase in total American consumption in the three years prior to 1937, and the growing use for wear resistant machine parts, other than for tools and dies, convinced his directors that ample provision must be made for future expansion. Likewise, it is known that Krupp's production in Germany is about 14 times the total of all carbide manufactured in the United States, not only due to its monopoly in a large trade area but to a considerably lower price, warranting more generous use in each particular application.

As to only one of the new uses being found in America: Deep sea fishermen buy so much tackle having hard carbide eyelets wherein to run their lines that an automatic pill machine is pressing them out by the thousand, believe it or not.

The spectroscope has been used for about 10 years in analyzing and controlling non-ferrous metals, especially where a trace of a deleterious element must be avoided, but the routine analysis of irons and steels, as outlined by F. E. Roach in Metal Progress, *June 1933, has awaited the development of a source, such as the spark here described, with which adequate reproducibility of intensities can be obtained. Rapid methods of developing, fixing and drying the photographic plates, of reading the line densities and transposing these readings into percentage content have helped to make the process much more valuable.*

ROUTINE SPECTROSCOPIC ANALYSIS IN FORD MOTOR CO. FOUNDRY

BY H. B. VINCENT AND R. A. SAWYER
Department of Physics, University of Michigan, Ann Arbor

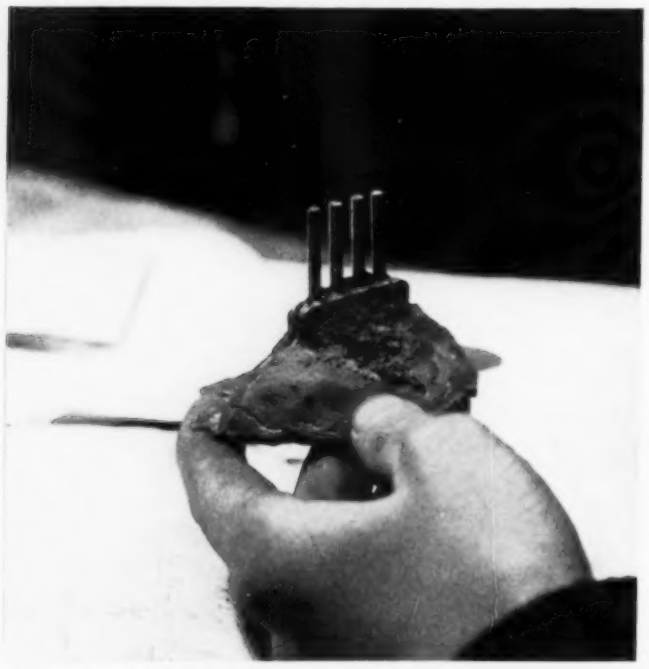
RECENT YEARS have witnessed remarkable extensions of the range of the physical properties available in iron and steel castings and a continuous growth of the field of utilization of new alloy cast irons and cast steels. Of these, numerous types are now poured to meet exacting specifications of tensile strength and hardness. Since the satisfactory performance of the product depends upon the uniformity with which the foundry can maintain its production to the specified characteristics, important new problems in control have arisen.

While numerous factors may affect the properties obtained in a casting, perhaps none is as important as the chemical composition of the alloy from which it is poured; improvements in other details can scarcely be expected to yield a satisfactory product from a faulty mixture. As the limits of tolerance have become narrower, the necessity has grown for improved methods of analytical control to meet adequately the needs of industry.

Since casting is usually a continuous rather than a batch process, the problem resolves itself into a control of the drifts or gradual changes in the composition of the melt in the furnace or cupola. The principal requirement of a satisfactory control system for a modern foundry involves the three following items: *(a)* The accuracy of the analytical determinations must be so good that the uncertainty is much less than the permissible variation in content. *(b)* The elapsed time between the pouring of the sample and the posting of the analysis must be brief; otherwise it is an inspection rather than a control. *(c)* The cost per analysis must be small so that samples may be analyzed at frequent intervals.

The authors have already demonstrated the possibilities of spectrographic analysis in the rapid, economical and accurate composition control of cast iron. In an installation made a short time ago at the Campbell, Wyant and Cannon Foundry Co. of Muskegon, Mich., and described in *Journal of Applied Physics*, 1937, page 163, it was shown that the spectrograph could furnish analyses with substantially greater speed than chemical wet methods could, with a resulting improvement in uniformity of product.

Along these same lines a spectrographic laboratory was developed a few months ago for the Ford Motor Co., whose outstanding activities in the development and improvement of alloy casting and continuous pouring technique have led to a demand for the closest possible control of composition. The number of samples to be



Chill Cast Sample From Foundry Melt. Test specimens are broken from sink head and dispatched with instructions to laboratory by pneumatic tube

handled was to be at least three times as great as in the earlier installation in Muskegon, and this larger volume of work, together with the greater variety of metal types and wider ranges of alloy concentration, led to new problems. The design, assembly and test of the necessary equipment was carried on by the Physics Department of the University of Michigan, through the cooperation of the University's Department of Engineering Research, and the installation now to be described is, at the present time, carrying a large part of the routine analysis of the foundry metals.

The process of analysis comprises the casting of suitable samples of the molten alloy, the burning of the sample with an electric spark, a photographic recording of the spectrum of the light produced, the processing of the photographic plate, measuring the density of selected spectral lines, and interpreting these readings into percentages by a calibrated transposing machine. Operations are carried out at such speed that the analysis of a sample may be posted within six minutes of the time it is received by the laboratory. The individual steps of the procedure are discussed below.

Samples are poured at each of the 26 cupolas, 20 electric furnaces and three air furnaces of the Ford foundry every hour (or oftener if necessary). Work is segregated so that one or more of these furnaces are melting continually metal for a certain part, say, the camshaft. The test specimens are four small pins about 0.15 in. diameter, cast in permanent steel molds where they chill so rapidly that segregation of the components is avoided and immediate removal of the cast from the mold is possible. Clerks at four stations in the foundry list the samples, break off the pins and dispatch them (with a notation of the determinations desired) by pneumatic tube to the spectrographic laboratory. The furthest foundry station is 660 yards from the laboratory, but specimens arrive in less than 2½ min.

On arrival, two of the test pencils are ground to a clean conical point on a small grinder and loaded into the spark apparatus with a jig as shown in the view opposite. This entire panel is contained in a cabinet, the door of which is a safety trap which must be closed during the operation of the spark; the operator is thus protected from the 40,000 volts of the spark circuit and from the ultra-violet light which might harm his eyes. A circuit diagram of the spark source would show that a condenser, charged by a transformer to 40,000 volts, is discharged through a circuit containing in series a synchronous interrupter, an inductance, a resistance and the sample gap. This electrical equipment is safely housed in a substantial case upon which the spark gap cabinet rests. Water cooling coils in the condenser, and heavy construction throughout, make possible continuous operation of the spark source. With jig loading of samples as shown, the equipment handles one pair per minute.

The discharge clamps are carried on rails attached to glass insulating panels. The rails permit easy adjustment, over a small range, of the distance between the spark and the spectrograph slit to compensate for the slight variation from batch to batch in the sensitivity of the photographic plates used. The accuracy and speed of operation of this type of spark source, which are thought to exceed substantially those of other discharge devices available at present, enable the laboratory to handle the large volume of work reaching it.

Light arises from the spark discharge crossing the 0.16-in. gap between the electrode ends. This light enters the spectrograph, a Littrow type quartz instrument, and its spectrum is recorded on a photographic plate. While as many as nine spectra may be recorded on a plate four inches wide, the actual number

recorded depends upon the number and nature of the samples received. For some of the casting processes, the analysis results must be returned as soon as possible, while for others, a slight delay is of less importance. Numerous spectra on a single plate save some photographic materials and operator's time, but extend the elapsed time required for results on the early samples exposed. In routine operation about six spectra are recorded on each plate. Spectra from samples where speed is less important are recorded first, leaving the last places on the plate for rush samples which may, and do, arrive in the interim.

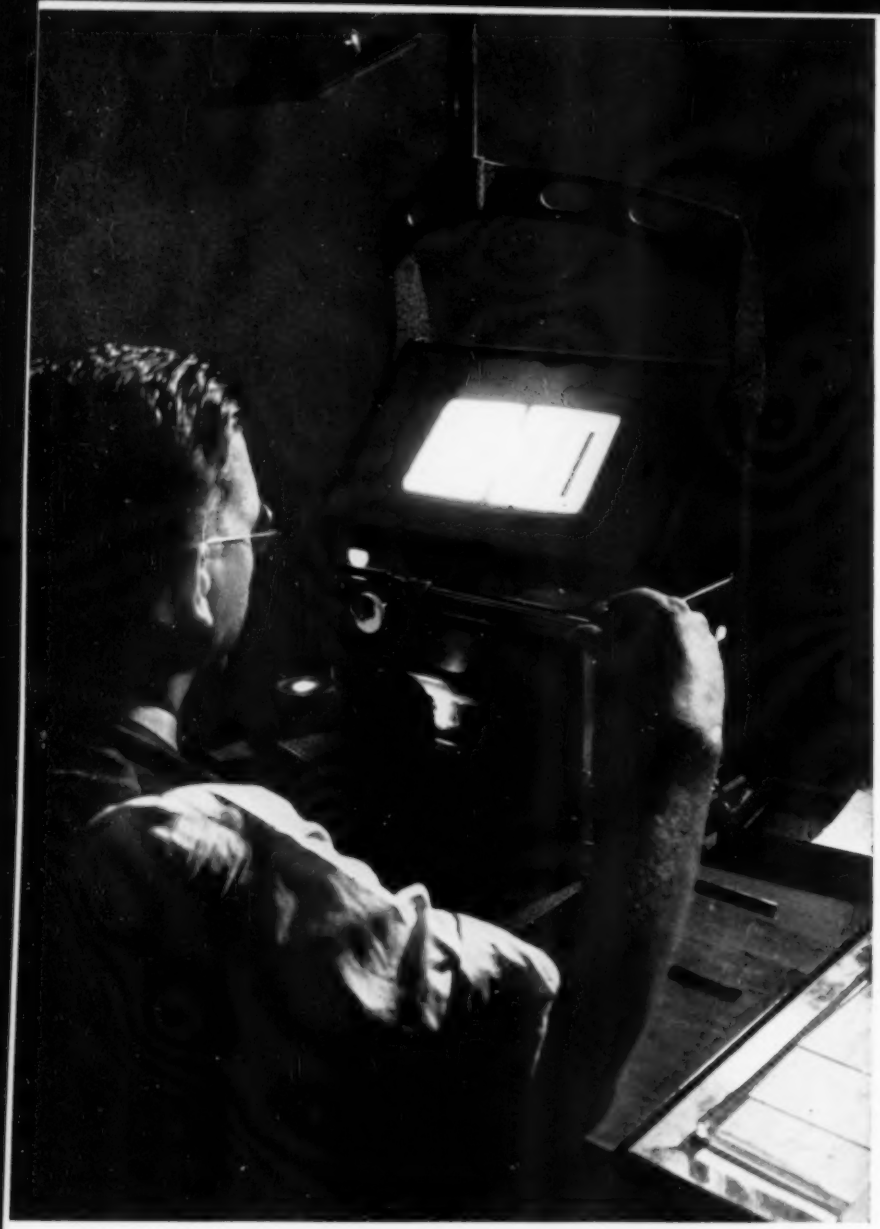
The exposed photographic plate is then processed and dried; efforts to make measurements on wet plates have proved uniformly unsatisfactory. All such processing in the dark room is carried out with apparatus developed especially for the purpose; solutions are contained in oscillating trays. Using, with some modifications, formulae mentioned in the literature, and special washing and drying devices, the plates employed in the routine work are processed and dried in about 4 min. Plates recently developed by one of the photographic manufacturers have been processed and dried in an elapsed time of 3 min.; these should make for even greater analytical speed.

Fixture Holds Two Electrodes A, Properly Spaced and Ready for Insertion in Clamps B, B'. Clamps are opened by pressing glass spacer C against springs at that end of pivoted bars D, D'. E is an air blast nozzle and F the supply pipe. High voltage is impressed by concealed transformers through terminals G, G'

Each of the spectra now recorded on the plate contains many of the lines of iron. In addition there are lines due to the other metallic constituents of the casting, and their blackening varies relatively to the iron lines according to the amount of the constituent present. With increasing chromium content, for example, the chromium lines get blacker and blacker. A comparison of the blackness of a chromium line with that of an iron line permits one to determine the concentration of chromium in the sample being analyzed.

Readings of the blackening of selected lines are made with the microphotometer shown in the halftone on page 38. The instrument is a commercial density comparator, remodeled in the Physics Instrument Shop at University of Michigan to give the required accuracy and speed of operation. A selected set of iron lines, whose relative intensities are known from previous measurements, is read in one of the spectra to establish for the whole plate the relationship between blackening and intensity of the incident light. In each spectrum a reading is then made on a chosen line for another element and on an iron reference line; this is done for each alloying metal whose amount is desired.

Through the medium of the established blackening-versus-intensity relationship, the readings are converted to percentage content by means of the transposing apparatus shown in the last view. This machine is a sort of slide



Microphotometer Utilizing Photo-Cells to Compare the Intensity (Blackening) of Selected Spectral Line for a Given Element With the Intensity of an Adjacent Selected Line of Iron

rule with scales drawn from readings on standard samples of which the composition is accurately known. Standard samples are read several times per day to check the accuracy of the scales and provisions are made for minor adjustments which are occasionally needed.

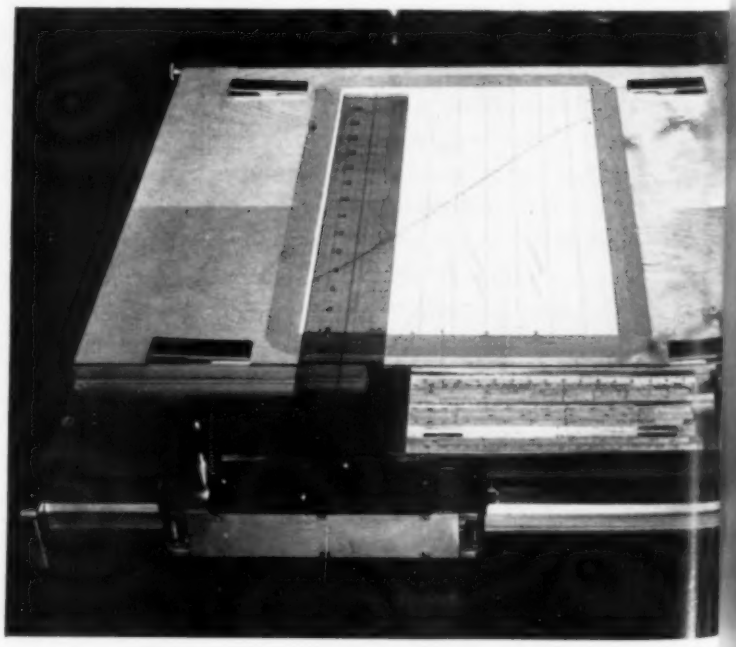
With the aid of the microphotometer and transposing equipment, the analysis of a sample for five elements is determined and duplicate records are written up in 90 sec. Results are returned to the foundry clerks by the pneumatic tube system. On rush samples, results can be returned in six minutes after receipt; seldom do samples handled in groups fail to be reported within 20 min.

The floor plan of the spectrographic laboratory at Ford's River Rouge plant is also shown. Samples arriving at the pneumatic tube station *A* are received by an operator who grinds the tips at the bench *B*, inserts them in the spark apparatus at *C* and starts the spark. In the darkroom a second operator attends to the recording of spectra with the proper exposure, order and spacing. He is responsible also for the processing and drying of the plate at the bench *E*. The dried plate is delivered to a third operator at the microphotometer *F*. While he makes the readings on the blackening of the chosen spectral lines, a fourth operator at the transposing equipment *G* reduces the readings to percentages of the various elements and, by pneumatic tube *H*, returns the results to the first operator at *A*. From here, results are distributed by the tube system to the foundry station from which the sample originated.

The reliability of the analysis is of fundamental interest, especially in view of the fact that the spectrograph would probably have been used earlier by the iron and steel industries if sufficient accuracy could have been assured. The best information on the reproducibility of analysis may be drawn from a series of determinations on a single sample. Such a series of silicon analyses, made on the same sample but on different days and on different photographic plates by different operators, is shown below. The readings were made at the University Laboratory with apparatus now in use at the plant:

Plate	Per Cent Silicon								
1272	2.07	2.02	2.02	2.03	2.01	2.03	2.03	2.02	
1275	2.07	2.07	2.01	2.05	2.02	2.01	2.01	2.00	2.08
1279	2.04	2.04	2.06	2.01	2.02	2.00	2.05	2.03	2.05
1281	2.05	2.02	2.02	2.06	2.02	2.06	2.08	2.07	

Slide Rule and Chart for Translating Microphotometer Readings Into Percentage of the Element in the Iron



Computed from the probability theory, the mean error of a single one of these determinations has a value of 1.18% of the amount present. Errors exceeding 5% of the amount present are not anticipated (their probability is less than one in 1000). Due to its metalloid character and relatively high concentration, silicon presents greater difficulties for adequate spectrographic analysis than do the metallic alloying constituents, and therefore the analyses for chromium, copper, manganese and nickel yield results at least equally reliable.

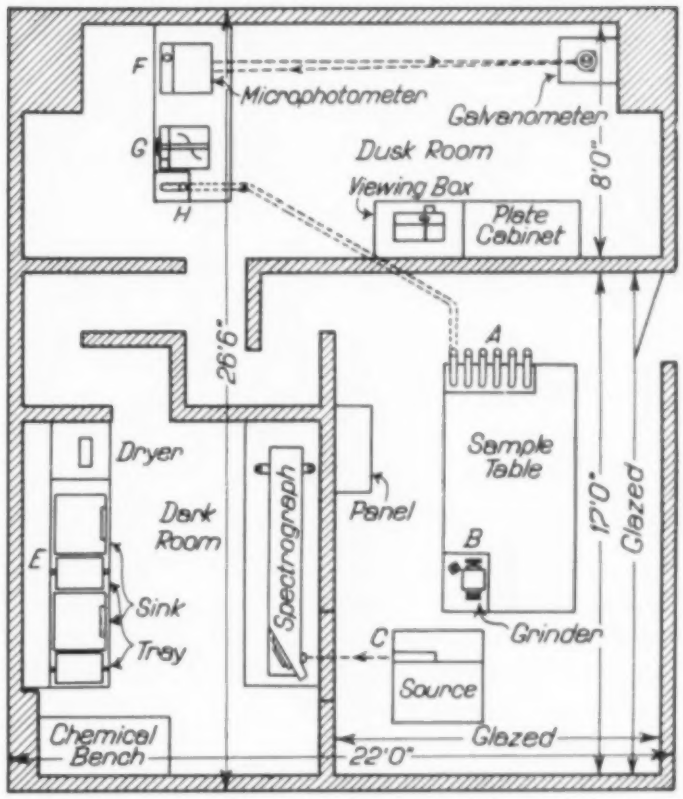
Among the analyses performed at the plant, certain specimens have been tested for silicon both in the spectrographic and in the adjacent routine chemical laboratory. The Ford chemical laboratory is outstanding for excellence in management, equipment and personnel; errors in its silicon determinations on castings may be expected not to exceed five units in the last significant place. The following readings were made on samples cast in pairs but, in most cases, not on the same piece of metal. Each pair of readings, therefore, represents an independent check on a new sample; none are repeated. They further demonstrate that no appreciable error exists through "salting" of the electrode holders.

Check Analyses for Silicon

Spectroscopic	Chemical	Spectroscopic	Chemical
1.47%	1.45%	2.70%	2.62%
1.48	1.45	2.51	2.46
1.52	1.51	2.49	2.48
1.57	1.59	2.23	2.17
1.47	1.50	2.87	2.90
1.41	1.38	2.77	2.76
1.51	1.50	2.80	2.81
2.06	2.12	0.61	0.56
2.36	2.41	0.53	0.52
2.46	2.51	0.62	0.66
2.29	2.27	0.92	0.95
2.17	2.09	0.89	0.90
2.32	2.27	1.00	0.92
2.19	2.19	0.97	1.03

In the matter of *reproducibility* of results, when the same test specimen is read a second time in the spectrographic laboratory, the following repeat analyses for silicon are typical:

Original Analysis	Repeat Analysis	Original Analysis	Repeat Analysis
1.40%	1.41%	2.31%	2.31%
2.94	2.91	2.32	2.34
2.20	2.20	2.55	2.59
2.04	1.99	0.65	0.64
2.31	2.34	0.89	0.90



Plan of Rooms and Equipment in Spectrographic Laboratory Capable of Analyzing, With Crew of Four Men, a Sample of Cast Iron for Five Alloying Elements Every 3 Min.

While further extensions may be made as required, the range of concentration for which the apparatus is now calibrated is as follows: Chromium 0.01% to 1.50%, copper 0.10% to 4.00%, manganese 0.15% to 1.50%, nickel 0.05% to 2.00% and silicon 0.10% to 4.00%.

The installation of the Ford laboratory was completed late in November 1938. Since that time, the load has been gradually increased as operators have been trained in the technique and have become familiar with the instruments. The laboratory is now handling over 300 samples in a 16-hr. day with two sets of operators; further increases are contemplated.

The handling of analyses for the blast furnace furnishes a concrete example of savings effected by the more rapid procedure. The heat in a train of ladle cars is held pending receipt of analysis for silicon and manganese to determine its destination, whether openhearth shop or foundry. The new laboratory saves some 15 min. demurrage per heat.

It is anticipated that laboratories of this type will find a continually broadening field in routine control of composition of iron and steel.

A NEW FOCUSING DEVICE FOR MICROGRAPHY

BY R. L. DOWDELL AND C. H. GREEN
Institute of Technology, University of Minnesota, Minneapolis

IT HAS LONG BEEN KNOWN that the proper focusing of metal or other structures with objectives of high numerical aperture is of paramount importance in obtaining the best photomicrographs.

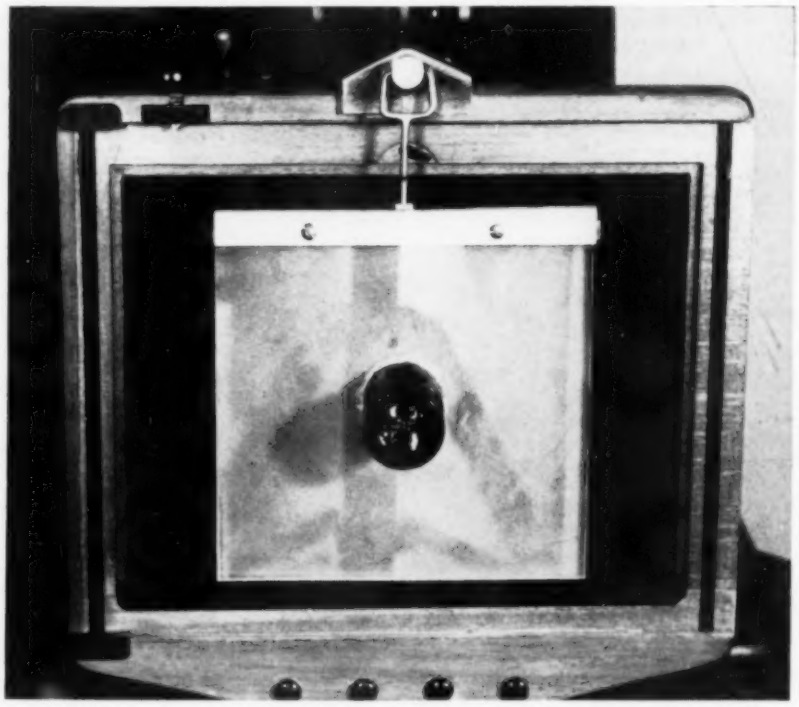
As the resolving power of an objective increases, focusing becomes more sensitive so it is considered good practice to focus images on the so-called plain glass slide with a magnifier. When the apertures of the diaphragms have been reduced and there is not too much light coming through the lens system, there is considerable advantage in using the magnifier for sharp focusing. This can be done as well, or better, by holding the magnifier in mid-air but it is tedious to hold it there without support and difficult to keep it in the plane of the film.

The focusing device shown in the accompanying photograph and sketch was devised in the metallographic laboratories at the University of Minnesota and has been in use since December 1938. Its use is found to save fatigue to the microscopist, and to be more exact and considerably faster than the old method.

One important advantage in our arrangement is that the magnifier is always in position. Most such work is done in a dimly lighted room and with this arrangement the microscopist does not have to hunt for the focusing glass in subdued light. It is where is should be, fastened into a piece of plate glass ground on the side nearest the lens system, and is always focused directly to the plane of the photographic film or plate. With this device considerable time can be saved because it is always balanced so that it hangs in the proper plane and eliminates the necessity of slipping in a ground glass slide to view the complete structural field to be photographed.

Although the focusing magnifier is mounted rigidly in the plate glass, the whole combination

Ground Glass Hangs Freely in Plane of Focus and Carries a Magnifier to Aid in Focusing for a Sharp Image



is flexible in the sense that it swings in two directions from a pivot suspension. Most microscopes show a visual field which does not correspond exactly to the projected field in the plane of the plate, making it necessary to shift the specimen slightly so that the proper field may be photographed. Consequently it is desirable to have a "floating ground glass" rather than merely a "floating magnifier".

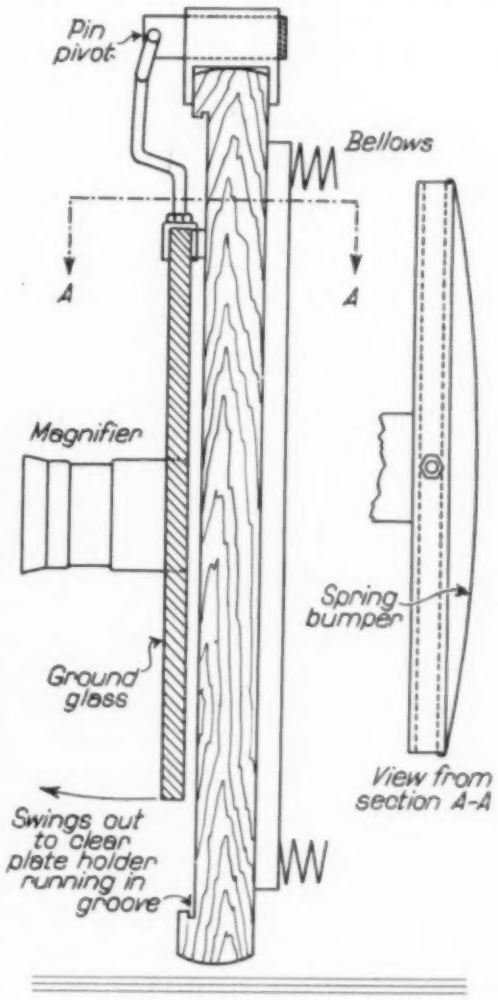
A somewhat similar device was patented by A. S. Grant (No. 983,047, Jan. 31, 1911) with the idea of holding the magnifier in place, but most of the intended advantages were lost in his rigid mount, so that the slide and magnifier must be removed in order to put in the plate holder.

The focusing magnifier with the floating ground glass is easily assembled by calking with lead or some fibrous material. These magnifiers are adjustable so they can be focused to the exact plane of the film and when once adjusted will remain so.

Any microscopist will readily see the advantages of a device of this type and note that there is far less chance of moving or disturbing the focus when sliding in the plate holder behind the arc of the spring bumper shown in the sketch, which automatically pushes the device away.

The device is of service only with cameras having a vertical back. It is fastened to the back frame of the camera by setscrews so it can be easily removed when photographs are not required. It can also be removed quickly by taking off a setscrew at the end of the journal or pivot, and the journal together with all of the hanging parts removed as a unit. A vertical adjustment might be desirable but we have not found it necessary because the operator swings the magnifier in an arc having a radius of 5½ in. from one side to the other so as to traverse the ordinary film.

Side View of Focusing Device Indicating Method of Suspension, and Sectional Plan Showing Spring Bumper to Push Device Aside When Plate Holder Is Placed in Position



CASTING STEEL BY DURVILLE PROCESS

BY L. NORTHCOTT

Abstracted from The Engineer, *May 26, 1939, p. 659*

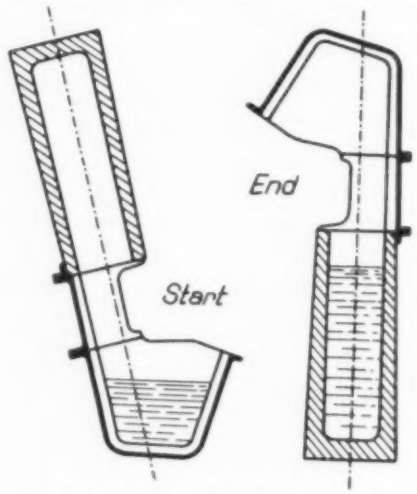
THE STANDARD METHOD of casting steel into an ingot mold utilizes a bottom-teeming ladle. This method results in splashing and turbulence of the molten metal in the mold and in the injection of oxide and gases, the escape of which tends to be hindered by the entry of fresh metal and by the solidification of that already cast. Less splashing and turbulence are believed to occur in the bottom-casting process, but at the expense of increased complication due to runners and the production of additional scrap.

An entirely different method was patented for the casting of aluminum bronze by P. H. G. Durville in order to avoid the surface defects to which non-ferrous alloys containing aluminum are liable. This is achieved by preventing turbulence. The mold is connected to the ladle by means of a trough in such a manner that the lower edge of the ladle, the base of the trough, and the lower side of the mold are in a straight line. These units are attached to trunnions so they can be rotated as shown in the sketch on page 42.

Development work at Woolwich Arsenal (summarized in Chapter 14 of "The Casting of Brass Ingots" by Reginald Genders and G. L. Bailey) showed that an important advantage of the Durville process was the ability to fill the mold with metal at a low superheat, thus insuring a reduction in ingot porosity and crystal size. Such low temperatures in

normal casting would lead to unsoundness due to entrapped air, and to the freezing of the metal near the nozzle and stopper in the ladle. Exploratory work on the application of the Durville process to the casting of small steel ingots has now been carried out.

In this work 60-lb. ingots, 4.5x4.5 in. cross-section, were cast into undressed molds from eight heats of medium steel with carbons ranging from 0.32 to 0.56%. One contained 2.85% nickel and 2.10% chromium; another contained 0.93% chromium and 1.30% aluminum; two others contained 1.25% aluminum (one with normal manganese, the other with 1.36% manganese); the remaining four had normal residuals of 0.01 to 0.03% aluminum. The steel was made in a side blown acid converter and killed by additions of ferromanganese, ferrosilicon and aluminum. One Durville ingot and one normal ingot were cast from each heat. Temperatures were not measured, but the rotation of the Durville mold was delayed for half a minute after filling the receiver. The direct-cast ingots were poured through a cup having a 1-in. nozzle. Time taken to fill the mold varied from 7 to 10 sec., and the rotation of the Durville mold took an additional 6 sec.



Molten Metal Held in Ladle Enters Mold Without Splash by Gradual Tilting of Device

From each ingot an axial slice ½ in. thick was cut, one face being the axial face. A sulphur print was obtained and then the macrostructure developed by deep etching. In these small ingots large-scale segregation was almost completely absent. Macrostructures and sulphur prints clearly show the complete absence of columnar structure or "ingotism" in the Durville ingots cast at a low superheat, as compared with the coarsely columnar crystal structure of the others. Microscopical examination of representative samples showed the presence of a fair quantity of non-metallic inclusions in all, but in every instance there appeared to be fewer in the Durville ingots.

Samplings from the sawdust from the slicing machines were analyzed for the usual elements. The steel cast direct has a slightly lower carbon and silicon content than the Durville-cast ingots except in the high aluminum alloys; it is suggested that the aluminum has prevented the formation of iron oxide and thus the oxidation of carbon and silicon by reaction with FeO, and also that this reaction, even when it does take place in the absence of much aluminum, is less prone to occur in the Durville process than in the direct method, owing to the decreased turbulence.

Tensile test pieces were then cut from the axial slices, some parallel to the surface and near the surface, some along the axis, and some transverse to the axis.

Durville ingots always gave 2500 to 5000 psi. higher values for the proof stress, and (with three exceptions in axial positions) from 1000 to 10,000 psi. higher values for ultimate. This is considered to be due, at least in part, to their slightly higher carbon and silicon contents. This difference in composition does not appear to have affected the ductility adversely, except in the nickel-chromium steel, of which the percentage elongation is less than that of the direct-cast ingot. While values of the proof stress were quite constant for all specimens from a single ingot, consistently higher results were obtained for the ultimate stress and elongation with those test pieces cut from the outside of the ingot than with those cut from the center. This loss is certainly largely due to porosity, which was generally more pronounced in the direct-cast than in the Durville-cast ingots. As might be expected, the lowest values were found for the test pieces cut vertically from the center of the ingot, since in this instance the whole length of the test piece was prone to slight sponginess. Similar comparisons may be made for heat treated test pieces.

It was concluded that this process, originally devised for the non-turbulent casting of non-ferrous alloys, can be applied with advantage to the casting of small steel ingots of high quality alloy or toolsteels, where freedom from segregation and coarse crystal structure, and perhaps also a superior surface quality, are required. Its principal advantage is the ability to cast at a sufficiently low superheat to insure a crystal structure which is wholly small and equi-axed, thus reducing segregation and "ingotism".

Seventy-five years ago a scientific dilettante, Henry Clifton Sorby, scion of a Sheffield family rich in the cutlery trade, turned his skill acquired during 15 years of microscopic work on rocks to study the inner structure of steel. However, his 1864 lecture "On Microscopical Photographs of Various Kinds of Iron and Steel" was so lightly rated by the British Association for the Advancement of Science that it rated a 10-line notice. Years after that, in 1887, the Iron and Steel Institute "took as read" and without discussion Sorby's first paper "On the Microscopical Structure of Iron and Steel" that contained a micrograph.

METALLOGRAPHY'S DIAMOND JUBILEE

COLORS in autumn leaves and birds' eggs, the spectrum of blood, units of length used by ancient craftsmen, cataloging of marine life, the structure of rocks and of steel — that HENRY CLIFTON SORBY could engage in scientific research in such an unrelated assortment of subjects and become famed as the founder of two important sciences attests the value of wealth and leisure combined with scientific curiosity and inventiveness.

Born 1826 to a family connected with the Sheffield cutlery industry since the 16th century, SORBY was educated at Sheffield Collegiate School and by private tutors. He published his first paper in 1847 at the age of 21, on agricultural chemistry. Two years later he prepared a thin rock section, the first ever examined by transmitted light, and thus founded the science of petrography. It was in this branch of geology that SORBY was best known, and for which he received numerous honors.

The work on metals which is commemorated by the metallographer's term "sorbite" was a byproduct of his geological studies. The examination of rocks under the microscope led to the study of meteorites; to throw light on the origin and nature of meteoric iron, the young Englishman resorted to the microscopic examination of artificial irons and steels.

Realizing immediately the significance of what he found to the steel industry from which he derived his fortune, SORBY set his mother, her butler and maid to work polishing steel samples — a laborious process in those days. These he was able to examine and photograph under the microscope by means of illuminators contrived by himself and others, and in 1864 he announced his results before a meeting of the British Association for the Advancement of Science. They met the fate so often accorded to new discoveries, however, and all that remains of this momentous contribution "On Microscopical Photographs of Various Kinds of Iron and Steel" is the following brief abstract from the *Report* of the British Association for the Advancement of Science, 1864, Part 2, page 189:

"The author first briefly explained how sections of iron and steel may be prepared for the microscope so as to exhibit their structure to a perfection that leaves little or nothing to be desired. He then exhibited a series of microscopical photographs taken under his direction by Mr. CHARLES HOOLE, illustrating the various stages in the manufacture of iron and steel, and described the structures which they present. They show various mixtures of iron, of two or three well-defined compounds of iron and carbon, of graphite, and of slag; and these, being present in different proportions, and arranged in various manners, give rise to a large number and varieties of iron and steel, differing by well-marked and very striking peculiarities of structure."

This year, then, is the 75th anniversary of the first publication or public showing of a photomicrograph of a metallic structure.

Some references have been found to a lecture "On a New Method of Illustrating the Structure of Various Kinds of Steel by Nature Printing", before the annual conversazione of the Sheffield Literary and Philosophical Society, in February 1864. This had nothing to do with

the microscope, but to an invention of SORBY's of deep etching a smoothed sample and using it as a printing block to record its macrostructure.

In that same year is a short paper "On the Microscopical Structure of Meteorites" in the *Proceedings* of the Royal Society of London, Vol. 13, p. 333, which might also be regarded as a "first". It would not class as a paper on metallography, as he discussed the stony or non-metallic meteorites, and compared the minerals they contained with those in volcanic rocks.

While SORBY's fame as a geologist, petrographer and microscopist grew world wide, nobody seemed much interested in what the microscope might be able to tell about the structure of man-made metal. More than 20 years passed and we suddenly find, in 1886 and 1887, two papers in the *Journal* of the British Iron and Steel Institute, contributed at the request of Dr. JOHN PERCY, then president of the Institute, who in the discussion of the first one stated that he had "a strong impression that, from a scientific point of view, great results were likely to flow from this line of investigations, which might possibly admit of valuable application in the manufacture and working of steel" — a conservatively worded statement not likely to damage his reputation as a prophet.

The first article "On the Application of Very High Powers to the Study of the Microscopical Structure of Steel" is reprinted herewith. In it he speaks of "my lecture at the last annual meeting", but this is not noted in the Institute's journal. That the whole matter was regarded somewhat lightly even by the steelmasters of the 80's may be surmised from the fact that the long paper in 1887 "On the Microscopical Structure of Iron and Steel" — the first printed publication of photomicrographs — was "taken as read", that is, passed by without discussion.

Two photomicrographs are reproduced from the paper of 1887, where they appear as photographic prints pasted individually into each copy of the *Journal*. This longer paper can be read with profit, since it shows again how excellently this lone investigator understood the things he was looking at. The materials mentioned in the 1886 paper, printed below, and called "free iron", "pearly constituent", and "intensely hard compound" are, of course, readily recognized as ferrite, pearlite and cementite.

SORBY died March 9, 1908 at the age of 82, first citizen of Sheffield, rich in awards, medals and honorary degrees. While most of these honors were in the fields of geology, mineralogy and petrography, the significance of his metallurgical work was recognized in an obituary published in *Nature:* "Dr. SORBY placed in the hands of metallurgy for all time a new and most valuable method of scientific investigation."

ON THE APPLICATION OF VERY HIGH POWERS TO THE STUDY OF THE MICROSCOPICAL STRUCTURE OF STEEL

BY H. C. SORBY, LL.D., F.R.S., &c.

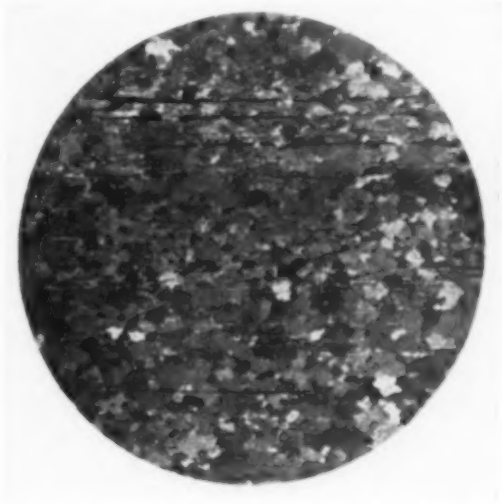
THOUGH I had studied the microscopical structure of iron and steel for many years, it was not until last autumn that I employed what may be called *high powers*. This was partly because I did not see how this could be satisfactorily done, and partly because it seemed to me unnecessary. I had found that in almost every case a power of 50 linear showed on a smaller scale as much as one of 200, and this led me to conclude that I had seen the ultimate structure. Now that the result is known, it is easy to see that my reasoning was false, since a power of 650 linear enables us to see a structure of an almost entirely new order, and of such a character that, if it had been on a scale of a quarter or a half the actual magnitude, it would probably never have been recognised, on account of being beyond the resolving power of the microscope for fine parallel lines.

The illumination employed is that contrived many years ago by the late RICHARD BECK, and consists of a thin plate of glass adapted above the object-glass, inclined at an angle of 45° to the axis, reflecting light down through the object-glass, which acts as its own condenser, and transmits freely enough the light passing back again to form the image in the eye-piece. With this arrangement, high powers give as good, or even better, illumination than low. Speaking generally, a power of 650

linear is about ten times that previously employed, which is, of course, enough to open out a new field for research. This great increase has, however, shown little or nothing more in the case of malleable iron containing little or no carbon, or in the case of the intensely hard constituent of spiegel iron, of white refined iron, and of blister steel. It has also shown but little more in the case of enclosed slags, or of the graphite in cast iron; but it has enabled me to see to great perfection crystals which are probably silicon, and has thrown a flood of light on the nature and character of that constituent of steel which in my lecture at the last annual meeting I described as the *pearly* compound. High powers show that it really has a structure closely resembling that of pearl, the surface being marked by fine straight or curved parallel lines, due to the presence of alternating very thin plates of varying hardness. After only a few hours of observation, I felt almost certain that these thin plates were iron free from carbon, and the intensely hard substance seen so well in blister steel; but the facts were so extraordinary, and so unlike anything I had ever seen or heard of in any mineral substance, that it was not until after several months devoted to the careful study of all the chief kinds of iron and steel that I felt confidence in the results.

The chief facts are best seen in the case of an ingot of steel of medium temper. On fracture, comparatively large crystals are visible, radiating from the surface to the interior. When a properly prepared microscopical section is viewed with a moderate power, it is easy to see that, after having crystallised out from fusion at a high temperature, these crystals break up on further cooling into much smaller, as described in my lecture. What is now seen with very high powers is that these smaller crystals finally split up into alternating very thin plates. Taking all the facts into consideration, it appears as though a stable compound of iron with a small amount of carbon exists at a high temperature, which at a lower breaks up into iron combined with a larger amount of carbon, and into iron free from it. If these two products had not differed so much in hardness, or if the alternating plates had been considerably thinner, or if definite plates had not been formed, such a compound structure would never have been suspected. It has probably never been specially looked for in other substances, and might exist without being visible, even with the highest and best magnifying powers.

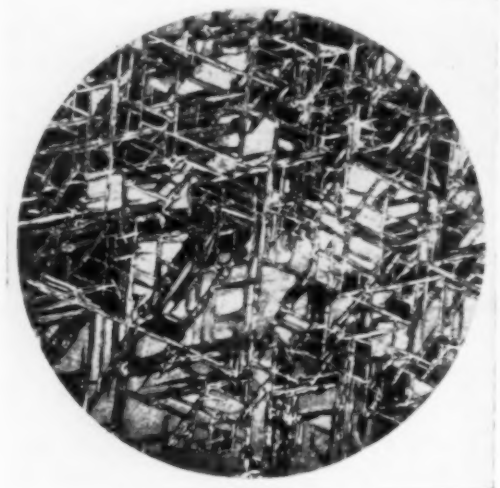
In those cases where no subsequent segregation has occurred, these alternating plates are often remarkably regular and uniform in thickness; and, as far as I am able to judge, the softer plates are about double the thickness of the harder. If so, we may say that the thickness of the softer plates is about 1/40,000 of an inch, and of the thinner 1/80,000, thus giving well-marked stria 1/60,000 inch apart. To define even these requires very careful adjustment of the object-glass; and considering all the circumstances of the case, it could not be expected that the two bounding edges of the thinner hard plates could always be defined, so as to show a flat intermediate surface. We are, in fact, brought face to face with an optical difficulty, depending on the considerable length of waves of light compared with the objects under examination, and are obliged to infer the nature of the very finest structure from what is seen when it is somewhat coarser. In some cases it is easy to trace the gradual passage from these extremely thin plates up to those which are sufficiently thick to show clearly that the structure is due to thin plates of the hard substance between soft iron. No mere cleavage would explain all the facts, though it is extremely probable that the direction of the alternating plates was determined by the previous crystalline structure. In some cases the plates are less well marked and the structure is more granular.



Bowling Bar-Iron, Longitudinal Section, Magnified 9 Linear

To give a good idea of the size of the plates, I would refer to what is seen in a longitudinal section of medium steel forged from an ingot 3 in. in diameter down to a bar 1 in. square. When broken, it shows a very fine grain; and when a prepared section is examined with a moderate power, this grain is seen to be due to crystals often about 1/1000 inch in diameter, which are not drawn out or distorted, as they would have been if they had existed previously to final cooling after hammering, and as they are distorted if the steel be hammered at a lower temperature. Examined with a power of 650 linear, these crystals only 1/1000 inch diameter are seen to contain something like 60 of the alternating plates, and even this extremely delicate structure shows little or no trace of distortion. Of course it is impossible

to separate and analyse such thin plates, and we must rely on induction to furnish us with a knowledge of their nature. My reason for concluding that the hard plates contain combined carbon is that they are not seen in iron free from carbon; they increase in amount with increase of carbon, and are seen to the greatest perfection when there is a considerable amount in a combined state. With an increased amount of carbon, comparatively large more or less solid plate-like crystals of the hard compound may be formed before the rest of the steel crystallises, or the excess of it thrown off to the surface of the crystals. In partially decarbonised white cast iron the thin plates are sufficiently thick to show perfectly well that the hard plates are continuous with portions of the original hard white constituent, and the soft plates continuous with the soft malleable iron free from carbon produced by decarbonisation. These two substances differ very greatly, and apparently are perfectly stable both at a high and a low temperature, whilst the facts already described show that an intermediate compound exists at a high temperature, and, under certain conditions, easily breaks up into a mixture of the other two at a lower.



Meteoric Iron, From Tazewell, Magnified 9 Linear

The relation of this unstable compound to all the different kinds of iron and steel is too complex to be described now, but I may say that, when no graphite is present, a long-continued moderately high temperature may cause the two constituents to segregate into comparatively thick and irregular plates of the hard compound and aggregations of free iron; whereas when graphite is present, the combined carbon appears to be set free, crystallising out as graphite and leaving free iron. This is one of the most important differences between steel and cast iron.

It also seems to me that this remarkable constituent probably plays the chief part in the hardening of steel. What I have been able to see with high powers shows that when strongly reheated the constituents again combine, and when suddenly chilled there is no evidence that they separate, though it is *possible* that this may be because the particles are too small to be separately defined. It, however, seems to me very probable that in the hardening process the unstable compound may not break up into soft iron and the very hard and brittle substance, but may be suddenly fixed, so as to give great hardness combined with strength. According to this view, the peculiar properties of Mushet's self-hardening steel may be due to the presence of tungsten preventing this usual separation. That the softening of hardened steel depends on a separation of the two constituents seems proved by what is easily seen when the heat has been maintained for a considerable time. In attempting to solve these questions, it is quite clear that we shall have to face difficulties depending on the comparatively coarse structure of light itself. Allowance must also be made for mechanical imperfections in my preparations, though, strange to say, these do not seem to be anything like so important as might have been expected.

The only other point to which I need now refer is the presence in some samples of cast iron of numerous very perfect and beautiful crystals of a kind invisible with low powers, being usually less than 1/1000 inch in diameter. They differ entirely from the comparatively large, somewhat irregular, plate-like crystals of graphite, though they sometimes occur in them. Some are of a beautiful ruby colour, and others of peculiar dark hue. The usual forms are triangles, rhombs, hexagons, and complex crosses. All seem to be modified conditions of the same substance. I have never seen anything like them in bar iron, and they are almost, if not quite, absent from good cast steel. Though further evidence is needed, yet, taking everything into consideration, it seems to me most probable that they are two different crystalline modifications of silicon. With high powers, some specimens of cast iron are seen to be complex mixtures of different substances, analogous to natural rock composed of several minerals. Some of these substances are quite absent from cast steel, which has a comparatively simple constitution.

It will thus be seen that the use of very high magnifying powers opens out a wide field for research, and has already placed a number of important questions in a new light. As far as I am able to judge, all the facts seen in the various kinds of iron and steel hitherto examined may be explained in accordance with the views here described; but the time spent in studying the fundamental questions prevented me from finishing a comprehensive illustrated memoir, already in large part written before using very high powers.

METALLURGY AT PITT HAS NEW QUARTERS

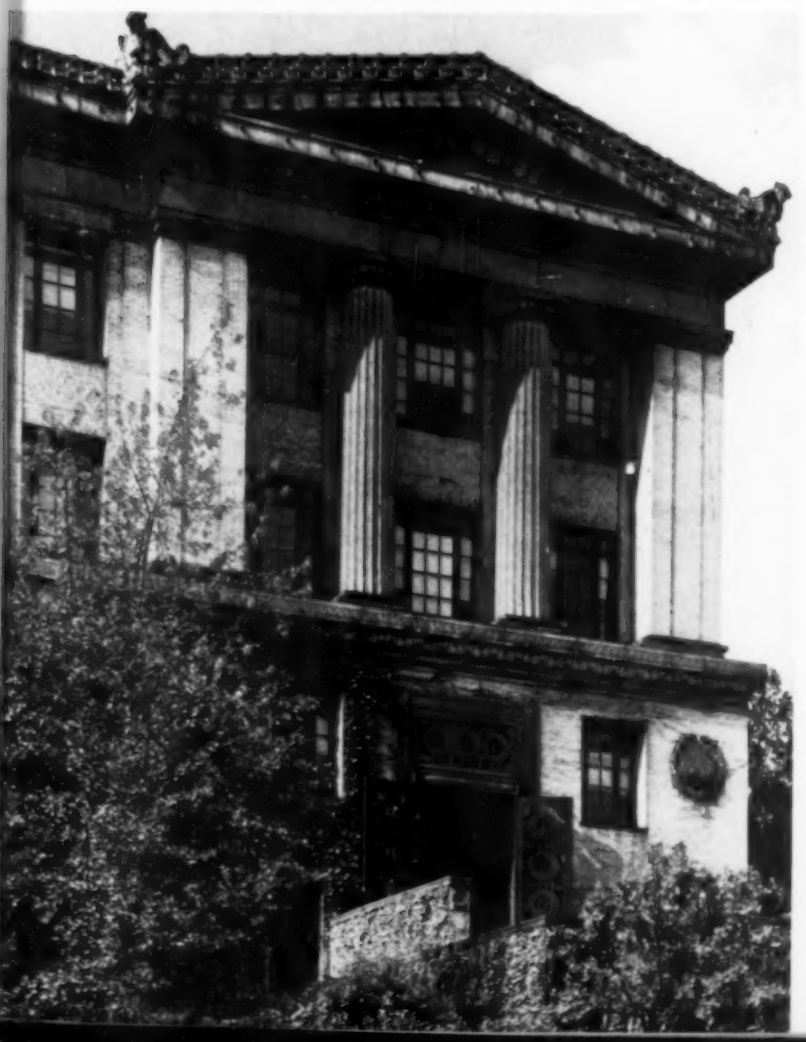
BY G. R. FITTERER
Acting Head, Department of Metallurgical Engineering, University of Pittsburgh

THE metallurgical engineering department at the University of Pittsburgh graduated its first class some 30 years ago.

Situated in the heart of the steel industry, this school has all the natural advantages of location. The obvious duty of such a department which draws its student body from this area is primarily that of fitting students for the steel industry. A recent survey indicated that about 95% of the graduates have entered the field of production metallurgy rather than consumption metallurgy, and their records in their chosen field are very good and therefore quite gratifying to the school.

The policy of the instruction has been and will continue to be to educate men for steel production work. No attempt has been made to emphasize research, although any student showing a natural tendency in this direction is encouraged to the fullest extent, and given every opportunity to develop. The metallurgical department is fortunate in that there are very good courses open to its students in some of the other departments of the University. Most of the students, besides their regular metallurgical work, take extra courses in physical chemistry, atomic physics, X-rays and spectroscopy, taught by professors in the chemistry and physics departments.

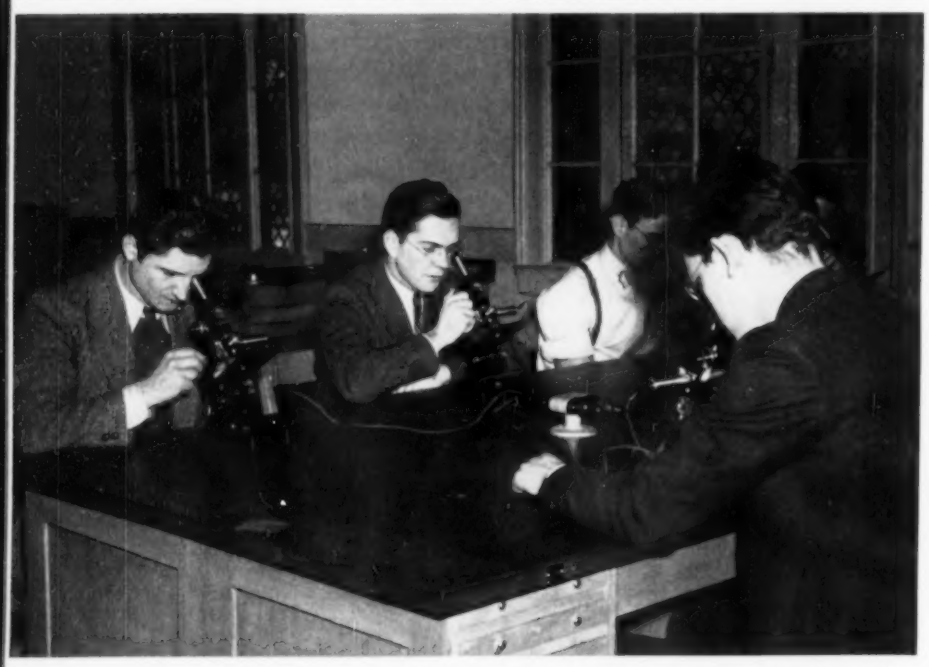
Entrance to State Hall, University of Pittsburgh, the New Home of the Department of Metallurgical Engineering



Enrollment Steadily Increasing

The metallurgical engineering department is fully accredited by the Engineer's Council for Professional Development and at the present time is one of the largest undergraduate schools in the country specializing in ferrous metallurgy. The enrollment has been increasing rapidly in the last three or four years until it is now about 100. There are 15 students enrolled in the present senior class.

Steady growth of the enrollment has required new equipment and enlarged space, and the University has met this demand by re-establishing the department with a new metallurgical laboratory on the first floor of



Most Examinations in Metallography Are Made Visually in a Combined Laboratory and Class Room Where Each Student Has His Own Microscope and Lockers

State Hall. Flexibility is one of the outstanding characteristics of the new layout.

One of the attractive features of the metallographical laboratory is the tables for students' microscopes. Three tables are provided and will accommodate a total of 20 students. Each student has a locked compartment for his individual microscope set, drawers for preservation of prepared specimens and others for notes. There are also individual electrical outlets. Micro-examination is possible at 100 to 500 diameters with the equipment available here, and this system of instruction greatly reduces the demand on the large photomicrographic apparatus. Because each student has sufficient equipment for routine examination of his specimens, photomicrographs may be taken on the large equipment when available. Desks, chairs and blackboard are also placed around this laboratory in such a way as to make this space usable as a senior class room.

Photomicrographic equipment is arranged in a semi-dark room. Two of the ordinary units are shown in the view at the bottom of the page, together with one of the newest compact types on the left. Adjoining this section are the dark rooms which are arranged to accommodate four students simultaneously.

A sample preparation room has been organized to handle as many as 20 students simultaneously. High speed cutting-off wheels, bakelite mounting press and nine wet wheels are provided. Other types of polishing units and material for hand polishing are also included.

Besides this adequate micrographical equipment, other laboratory facilities are of course available. These include arc and high frequency induction furnaces for melting, gas-fired melting furnaces, a large forging hammer, both arc and acetylene welding equipment, chemical and assay laboratories together with a machine shop. Complete heat treating equipment such as "hump" furnaces, electrolytic salt baths, and physical testing equipment — especially modern hardness testers — are also available.

It is planned that all of this latter material, of which most is now in another building, will soon be moved into State Hall, a floor below the new metallographic laboratory, so as to have all facilities together as a working unit.

Two Conventional Photomicrographic Equipments and One New Compact Type Are Installed in the Dusk Room for Photography

Advantages of differential hardening of large masses of metal by means of the oxy-acetylene flame are well exemplified in its successful application to the ways of lathe beds. An alloy cast iron, with composition chosen to give fully pearlitic matrix in the metal as-cast, is hardened in a single pass to scleroscope 79 at the surface, with structure merging by insensible gradations into the original about ¼ in. below. With manufacture under proper control, warpage will be on the order of 0.010 in. in 8 ft., and the ways are finally ground to a tolerance of 0.0005 in. After 3½ years' use such a bed shows no wear.

FLAME HARDENED LATHE BEDS

BY P. A. ABE

Works Manager, The Monarch Machine Tool Co., Sidney, Ohio

TODAY it is more than ever important that the ways of lathe beds be made extremely resistant to wear. With the development of stellite and carbide cutting tools, lathe spindle speeds are up to 5000 r.p.m. and cuts are being taken under heavy feeds never practical before. At the same time the demand is for machined parts of greater and greater accuracy; limits of half a thousandth of an inch are now fairly common practice even in high production plants.

All the other elements of modern machine tools have been improved to meet the new requirements. Practically all the bearings are anti-friction bearings. Shafts and gears are of alloy steels. A great many parts are hardened and ground. Yet until the recent application of the flame hardening process, no completely satisfactory solution had been found to the problem of wear on bed ways.

Lathe beds start to wear the very first day they are put into use and it is inevitable that the accompanying scoring, scratching and galling of the ways should impair and eventually completely destroy the machine's original accuracy and efficiency. Many attempts at solving the problem were made. At first, the iron along the way sections was cast against a chill. Then steel wear strips were tried. Then hardened and ground steel wear strips. Then the entire bed was made of welded steel construction. All offered certain improvements but we were not convinced that a completely satisfactory solution had been reached.

Chilling introduced intolerable internal strains; furthermore, because a chilled close-grained iron is not machinable, the low strength open-grained iron which was necessarily used lacked uniformity of hardness. Steel wear strips stand up reasonably well but they *do* score and wear, and since they are not an integral part of the supporting base, always are in danger of being loosened. An all-steel base of welded construction is expensive, it has no appreciable gain in increased life, and its ways must be hardened. Since machine tool bases are so large and irregular in shape and section, heat treating and quenching them in their entirety was out of the question.

About five years ago, realizing that bushings of practically the same alloy iron analysis as that used in our beds were being very successfully hardened from an electric furnace, we began experimenting with flame hardening. The first attempts were immediately promising but there were many difficulties to surmount.

The first difficulty, and the one which critics of the idea insisted would make flame hardening impractical for heavy duty lathes used for extremely accurate work, was that of distortion. Another difficulty was to get the required hardness without any possibility of the hardened

layer cracking, or spalling away from the unhardened metal beneath. With these difficulties solved there was the problem of grinding the long vee and flat way surfaces to the extremely close tolerances required.

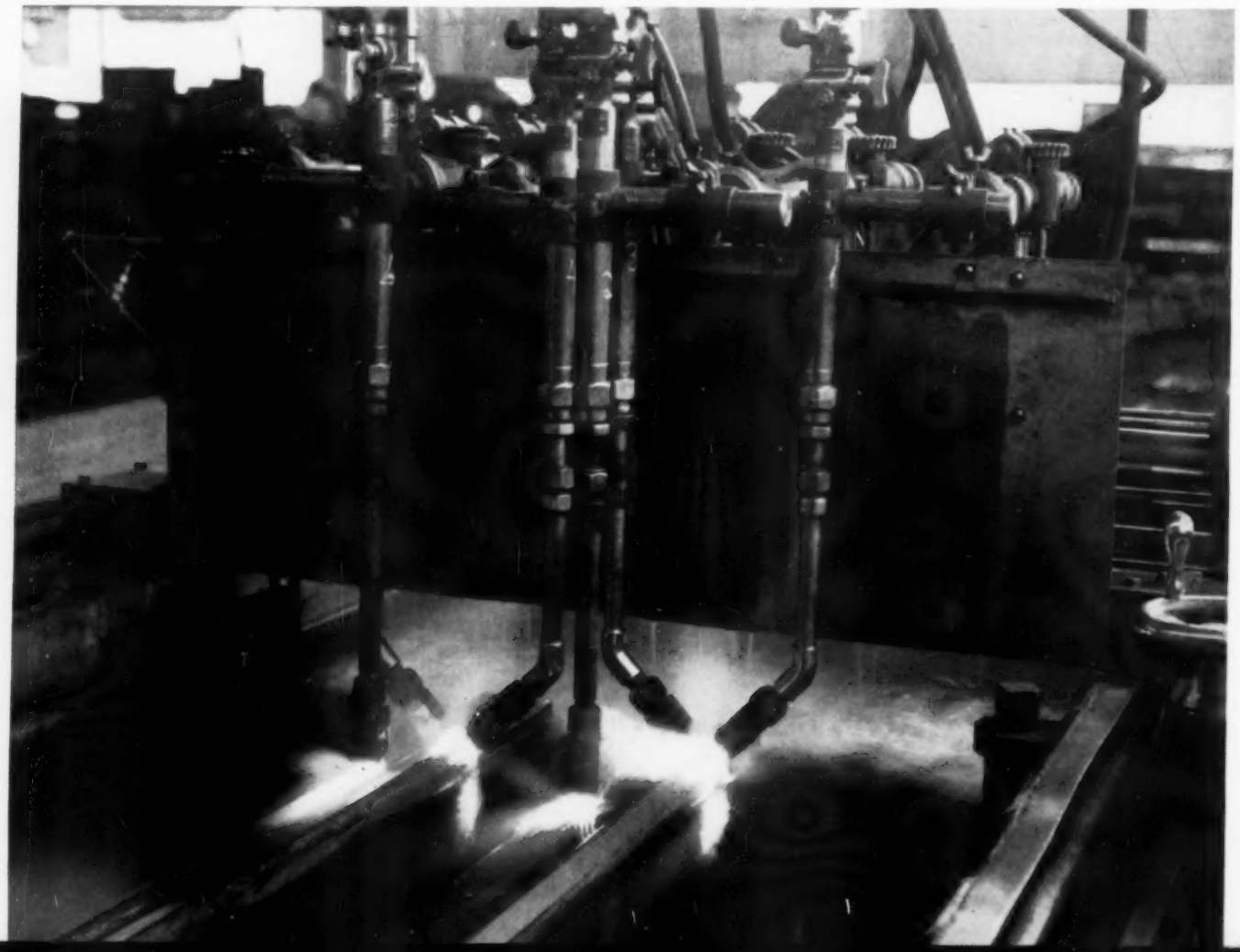
After 3½ years of experimenting and testing, these and numerous other difficulties were solved, the special equipment required was designed and perfected, and the production of flame hardened lathe beds is now a standard practice at the Monarch plant. Flame hardened lathe beds weighing as much as 7½ tons are being regularly produced with ways unmachinably hard and finished to a tolerance of 0.0005 in. The hardened surface has a fully martensitic structure which gradually blends into the pearlitic structure of the base metal so there is no definite line of demarcation or plane of cleavage which could result in chipping, and there are no appreciable internal strains in the castings. Tensile strength of the mass of the casting, which is of first importance in providing a good rigid foundation for the hard wearing surface, is specified to be from 45,000 to 50,000 psi. A test machine operating continuously day and night for almost 15 months shows no measurable wear or any scores or spalls or even scratches on the surface of the casting.

One of the most important factors making possible these results is, of course, careful control of the carbon and alloy in the iron.

Years ago, MOLDENKE pointed out that cast iron could be described as a steel matrix interspersed with graphite flakes and that therefore the steel matrix of the cast iron body will respond like steel to quenching. Since steels lose their hardenability progressively as their carbon content decreases, and since cast iron which contains considerable silicon precipitates most of its carbon as graphite, care must be taken to prevent this precipitation from becoming excessive and leaving behind an anemic body low in combined carbon.

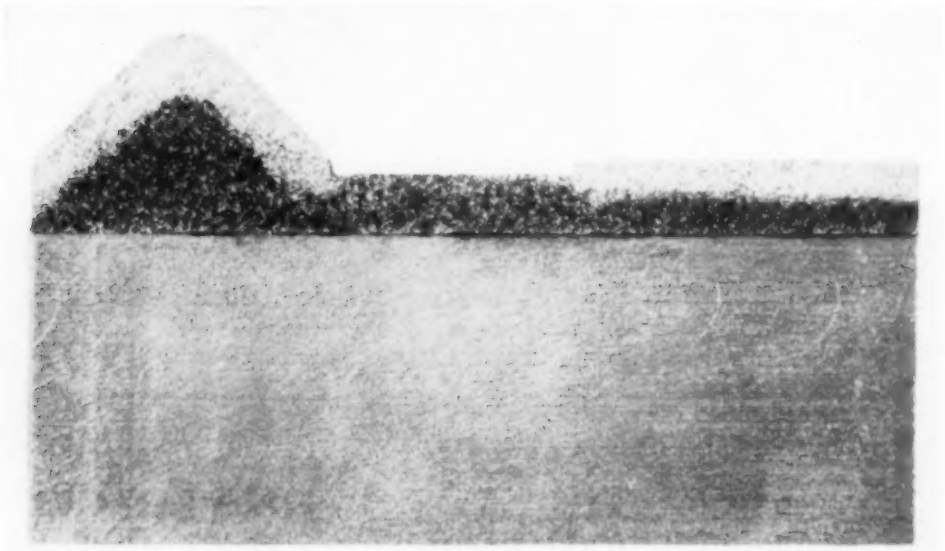
A combined carbon content of approximately 0.60% is therefore specified in the composition of our castings, an amount capable of giving the maximum hardness number in steel after quenching at maximum rates. To obtain the necessary fine adjustment between graphite and combined carbon, a closely controlled nickel alloy cast iron is used — an alloy in which a careful balance of nickel, silicon, manganese and molybdenum can be depended upon to eliminate hard spots of coalesced iron carbide and also to stabilize that portion of the carbide in the pearlitic matrix necessary for flame hardening to the fullest degree. The

Two Flat and Two Vee Ways on a Lathe Bed Are Hardened in One Pass by Six Oxy-Acetylene Torches. The casting is all but submerged in water; each torch is followed by a quenching jet



graphite flakes take no important part in this particular reaction.

This cast iron is especially low in phosphorus and sulphur to avoid the occurrence of hard phosphides or soft, tender sulphide films. The silicon, nickel and manganese provide the necessary balance for a proper graphite content and a tough, hardenable matrix. The mix to the cupola consists of 60 to 65% steel railroad rails and the balance pig iron of high grade with nickel and manganese added as needed to bring the amounts indicated. The composition is specified to run as follows:



A 5-In. Section of a Monarch Lathe Bed Is Sawed Nearly Through and Then Broken to Show Penetration of the Hardening Action

	Maximum	Minimum
Total carbon	3.20%	2.80%
Combined carbon	0.75	0.55
Silicon	2.00	1.70
Manganese	1.00	0.70
Nickel	1.50	1.00
Phosphorus	0.15	..
Sulphur	0.10	..
Chromium or molybdenum	0.25	..

Such an iron is composed of a fine pearlitic matrix, interspersed with well-distributed graphite flakes (see the bottom micro on page 52). It is a fully pearlitic matrix such as would occur in a high grade hard steel.

We have found that the lower the hardening temperature the less will be the distortion during flame hardening. Since the amount of heat applied to the very surface must be controlled to prevent fusing it or burning it, a low hardening temperature is obviously desirable. Consequently a low critical temperature in the alloy is desirable in order to get the greatest penetration for a given, fixed temperature. A lower heating temperature has a generally milder action and a more gradual blending with the underbody, resulting in a more evenly hardened surface.

It is well known that silicon, chromium and molybdenum raise the critical hardening range of iron-carbon alloys, while manganese and nickel lower it. Castings of the composition described above respond to heat treatment and can be fully hardened from a low temperature of about 1320° F. Thus, with cast iron containing nickel and manganese in substantial amounts and as little silicon as practicable we are able to produce castings capable of being flame hardened to the desired depth without resultant heat checking, and we are able to get a tough surface with the least distortion for the best surface hardness.

The moderate quantity of graphitic carbon originally present in the high grade "pearlitic" iron remains unchanged. We believe this to be an advantage, as it seems to provide reservoirs for lubricant in the hardened matrix, and increases the adherence of the oil film, which is very important in the lubrication of wearing surfaces on machine tools.

Beds are flame hardened in the specially designed water tank shown in the halftone on page 50. They are immersed in continuously circulated cold water, up to the underside of the ways. Six oxy-acetylene torches are used, one on each flat surface of the four ways. Quenching water jets are an integral part of the torches, being about ¾ in. behind the gas jets.

The carriage supporting the torches moves lengthwise over the tank at between 3 and 6 in. per min., depending upon the size of the bed being hardened and the depth of hard surface desired. The torches are given only one pass over each bed, and produce a hard, wear resist-

ing, firmly anchored, graphite-pierced surface, strongly fortified to resist the rigors of service.

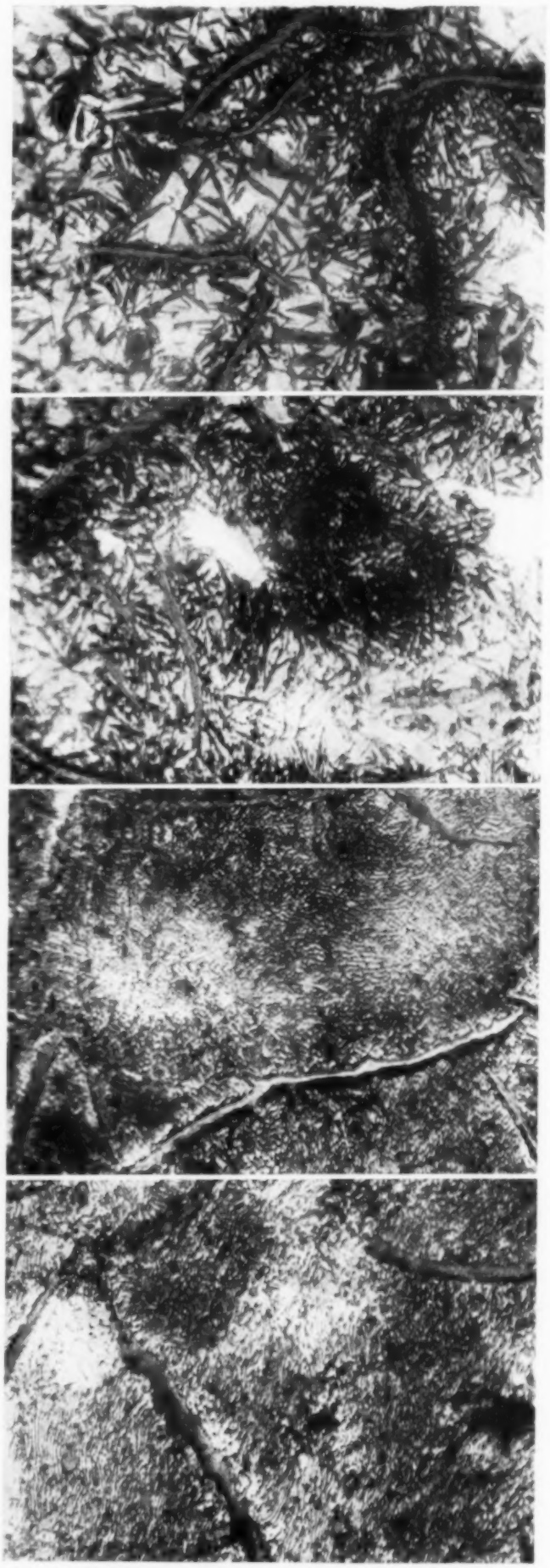
By localizing the heat at the burners by means of the circulating water bath, quenching with the proper water pressure, and making but one pass over the bed, distortion is held to a minimum. The average distortion in a bed 8½ ft. long hardened to a depth of from ⅛ to ¼ in. is approximately 0.010 in. This warp is then ground out; the final tolerance is 0.0005 in. in the over-all length. To provide stock for this grinding operation, an excess of about 0.010 in. of metal is left on the ways before hardening.

Exhaustive tests have studied the wearing qualities of the flame hardened surfaces. One is especially significant. Duplicate carriages, each loaded with weights totaling 500 lb., were put into continuous operation on two typical beds, one unhardened, the other flame hardened. A crank arrangement operated by an electric motor moved each carriage one foot of travel on each bed 20 times every minute. At frequent intervals cast iron dust was automatically dropped on the bearing surfaces. After 10,000,000 passes (one year of continuous movement) the unhardened bed was very badly scored and worn more than 0.005 in. over the entire area. The flame hardened bed showed no wear and was entirely unscratched.

To illustrate the gradual transition from the totally martensitic structure of the surface through the sorbitic to the totally pearlitic structure of the base, a way was taper ground over a 14-in. length and photomicrographed at ½ in. spacings. The structures at stations 1, 9, 19 and 29 are shown in the attached views. Shore scleroscope readings were 79, 69, 57 and 31.

To test the adhesive properties of the martensitic surface, test sections were flexed under hydraulic pressure and submitted to various impacts. In every case the entire test piece would fail before spalling.

One of the first beds flame hardened when extensive development of the process was first undertaken was built into a machine subsequently used under actual operating conditions in the tool room at the Monarch plant. This bed, after 3½ years of satisfactory service, in a recent check showed no measurable wear.



Micros From Way, Taper Ground, Show Structure of Surface of Way (Top), of Unhardened Base Metal (Bottom) and of Third Points in Between. Magnified 400 diameters

Three Committees on the general subject of Machinability of Steel are headed by Prof. Orlan W. Boston as general chairman and report to the Metals Handbook Committee. One of these is a sub-committee on cutting fluids, Joseph Geschelin, chairman, and a report from it was printed in METAL PROGRESS *in June, 1938. Another is considering the mechanical factors involved in the machinability of steel; its chairman is Hans Ernst. The third is on metallurgical factors and its preliminary report is, in the words of Chairman Graham, "only tentative, and worthy of comment and criticism by interested parties".*

METALLURGICAL FACTORS AFFECTING MACHINABILITY

BY H. W. GRAHAM, J. D. ARMOUR, PHILIP SCHANE, M. N. LANDIS

FACTORS that are responsible for variation in the operation of machining steel fall into two general groups: 1. Those that are inherent in the steel; 2. Those that arise from conditions in the cutting operations. It is the purpose of this article to deal only with those factors, metallurgical in character, which are in the steel. These factors fall naturally into groups relating to manufacture, composition, processing, and physical characteristics. There will also be presented an approximate classification of the machinability of various commercial grades of steel, and discussion is invited, especially as the committee is not in full agreement as to these ratings.

MANUFACTURE OF THE STEEL

Steel Making — Aside from the mere adjustment of analysis there are many features in the operation of any selected steel making process that will affect the machining quality of the final product. By empirical observation and experience it has been learned, for instance, that the machining quality of screw steels is generally favored by carrying the steel making process to a further point of oxidation of carbon than is done in making other steel products. Furthermore, any procedure that favors the absorption of an appreciable nitrogen content seems to be favorable to machinability. Machining quality also appears to be affected adversely if the final total sulphur content is made up largely by residual sulphur rather than by sulphur added in the final stages of the steel making.

The Bessemer Process — The development of free machining steels finds its origin in a fortunate combination of circumstances attendant on the early days of the bessemer process. Late in the 19th century it was recognized that high sulphur blows, erratically produced in the cupola-converter combination, made a product superior in machining qualities to openhearth steel. The introduction of the hot metal mixer, improved bessemer converters and the success of deliberate additions of sulphur to bessemer steel is now a matter of history.

The Openhearth Process — Openhearth screw steels are the result of an attempt to combine the superior machining qualities of bessemer screw steels with the advantageous properties of openhearth grades.

The Duplex Process — The duplex method of finishing bessemer-blown metal in an openhearth furnace imparts certain bessemer properties to openhearth practice. Duplex steel is generally superior in machining quality to openhearth steel made direct from scrap or from scrap and pig iron.

Composition

Composition of a steel has a major influence on its machinability, since it affects such characteristics as structure, physical properties of the various structural constituents, inclusions and hardness. Because the effect of composition is more or less indirect, it is difficult to state the exact influence of each element.

Carbide forming elements decrease machinability by increasing hardness, but their detrimental effects can be modified by proper annealing. Elements which form solid solutions with ferrite generally cause poorer machinability because of the hardness or toughness imparted by them. Elements forming inclusions have harmful effects when the inclusion is hard or abrasive, such as alumina or silica; elements such as sulphur, which form soft inclusions, are generally beneficial. A general statement of the effects of the more important elements and compounds is given below.

Carbon — Very low carbon steels are generally of poor machining quality. The best carbon content for machinability is approximately 0.10% for bessemer steel and 0.20% for openhearth steel. Cutting quality drops off rapidly with increase of carbon above 0.15% in bessemer and above 0.30% in openhearth.

Manganese — The effect of manganese is largely dependent on the total content of the hardening elements carbon, manganese and phosphorus. In the ordinary machining steels, the most favorable manganese content is approximately 0.75% in bessemer steel and about 1.00% in openhearth steel.

Phosphorus — In bessemer steel phosphorus should not be lower than 0.09%. Added phosphorus up to about 0.10% in openhearth steel is mildly effective in improving machinability.

Sulphur is the more generally used element for obtaining better machinability. Improved results are found as its content is increased up to some high limit not as yet determined, although from a manufacturing standpoint this limit is placed at approximately 0.30%.

Silicon — Cutting quality generally decreases as the silicon content increases, due chiefly to the silicate inclusions usually present.

Alloying Elements — The general effect of the regular alloying elements is a decrease in machinability on account of the hardness and toughness imparted to the steel. For this reason most alloy steels will require a special heat treatment, like annealing, to secure the best machining properties. Some alloys such as molybdenum, vanadium or chromium decrease machinability less than others such as nickel. Lead is added to steel to improve machinability and very promising results have been obtained. Selenium is added to stainless steels to improve machinability, its effect being similar to that of sulphur. Tellurium has also been added to improve machinability.

Inclusions — In accordance with the best accepted practice of screw steel manufacture, every precaution is taken to avoid abrasive inclusions in the finished product. Sulphides usually occurring in the form of MnS and oxy-sulphide variously diluted with FeS, MnO or FeO are generally accepted as benefiting cutting quality. Iron oxides and manganese oxides either singly or in combination are not believed to be detrimental. Their presence in high sulphur steels is usually associated with sulphur (oxy-sulphides) in which form they are considered to be distinctly beneficial. The combination of high percentages of these two oxides with SiO_2 is also said to reduce the abrasive and detrimental qualities of silicates. The presence of Al_2O_3 is considered definitely detrimental, due to its high hardness and abrasive properties. Silicates low in FeO or MnO content possess a high degree of hardness and are believed to exert a detrimental effect on machining quality.

Processing

Principal processing methods that affect the machining characteristics of steel are hot working, cold working, and thermal treatments.

Hot Working — Experience indicates that large structural grain size is generally preferable for most types of machining operations. The desired structural grain size can usually be obtained within reasonable limits by controlling the finishing temperature in hot working. For carbon steels finishing temperatures are held in

Approximate Machinability Classification

Free Machining Resulphurized Steels		Carburizing Steels				Heat Treating Steels	
		Non-Resulphurized Carbon Grades		Alloy Grades		Non-Resulphurized Carbon Grades	
S.A.E. No.	Per Cent	S.A.E. No.	Per Cent	S.A.E. No.	Per Cent	S.A.E. No.	Per Cent
X-1112	140	X-1020	68	3115	53	1030	62
1112	100	X-1015	65	3120	53	1035	62
X-1314	90	1020	63	6115	53	X-1040	62
X-1315	87	1015	53	6120	53	1040	60
1115	81	1010	53	5120	51	1045	48
1120	78	1025	53	2315	51	X-1045	50
X-1330	76	C-1025	53	2320	51	1050	45
X-1335	72			4615	51		
X-1340	70			4620	51		
				3215	49		

the neighborhood of 1700° F., or higher when machining characteristics are important and the steel is to be machined before being submitted to further heat treatment.

For alloy steels that have high hardness when finished at temperatures well above the upper critical point, temperatures just above the critical provide somewhat lower hardness (this decreases the rate of cooling through the critical) which may aid machining more than larger grain size with its attendant higher hardness.

The effect of hot working on machinability may be considered a minor influence compared to the effect of such factors as chemistry and annealing treatment.

Cold Working — Machining characteristics of most steels can be very materially improved by cold working. This improvement is due in part to the effect of cold working on the physical properties and partly to its effect on the structure of the steel. Machinability is favored by relatively low strength and low ductility. Cold working increases the strength but decreases the ductility, therefore, machinability of steel can be improved by cold working up to the point where the cold working increases the strength beyond the good machining range of about 187 to 217 Brinell. Cold work has its greatest improvement on steels that have a low order of work hardening and a high order of work embrittlement.

Thermal Treatments — The machining properties of steel can be markedly affected by heat treatment. Very low carbon steels, with carbons under 0.10%, can be improved in machinability by quenching in water from over the critical point, which lowers the ductility and reduces the tendency to drag in machining. Except for these very low carbon steels, however, quenching and tempering is very detrimental to machining properties; the tempered structure is one of the least favorable for machining.

Annealing and normalizing treatments can be very useful in improving the machining properties. In medium carbon steels they should be designed to coarsen the grain, break up the continuity of the ferrite as much as possible and put the carbide in the form of lamellar pearlite. At about 0.50% carbon, with this type of structure, the strength becomes too high for best machinability, and it is necessary to modify the annealing cycle so that just sufficient carbide will be spheroidized or divorced to keep the strength within the best machining range. This will be somewhere in the neighborhood of 100,000 psi. tensile strength or about 200 Brinell hardness. Otherwise the structural characteristics should remain the same. As the carbon increases above 0.50%, the percentage of carbide in the spheroidized form should increase until at about 1.00% carbon it is necessary to have practically all of the carbide in the spheroidized form to keep the strength factor within the best machining range.

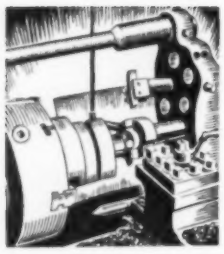
In the alloy steels the same general principles again apply but other factors must also be taken into consideration. Alloys such as vanadium may tend to form carbides, or, like nickel, to form solid solutions. Sometimes the same alloy may act in both ways — that is, go into solution in the ferrite and form a complex carbide. Examples are chromium and manganese. In this discussion the alloys will be considered under the two general classifications of carbide forming and solid solution forming.

The carbide forming alloys have the same effect on machining properties as does carbon, but because of their effect on hardenability, the carbon content at which the strength factor becomes too high for good machinability is lower than in the plain carbon steels. When heat treatments are used to lower the strength, the annealing cycle should be designed to produce a well broken up, coarse grained, lamellar pearlite. Spheroidizing part of the carbide in the higher carbon alloy steels is resorted to, just as in the plain carbon steels. It follows that carbide forming alloys give no particular difficulty in producing good machining properties in alloy steel.

The solid solution alloys present a different problem. They toughen and strengthen the ferrite and therefore their tendency is to retard machinability. Attempts can be made to produce a lamellar pearlite structure by thermal treatments (or lamellar with a certain percentage of spheroidized carbide), the same as outlined for carbon steels, but the characteristics of the ferrite matrix cannot be changed very much. It is more difficult to produce lamellar pearlite structure if much alloy is in solid solution in the ferrite, since such alloys make the transformation of austenite more

Approximate Machinability Classification

Heat Treating Steels Alloy Grades Not Annealed		Heat Treating Steels Annealed for Machinability Alloy and Carbon Grades					
S.A.E. No.	Per Cent	S.A.E. No.	Per Cent	S.A.E. No.	Per Cent	S.A.E. No.	Per Cent
3130	41	1045	60	4150	45	3150	40
3135	38	1050	57	3140	45	6150	40
6130	35	4130	55	6140	45	5150	40
2330	35	3130	55	2330	45	2340	40
X-3140	33	4135	52	X-3140	43	T-1335	40
2335	33	4140	50	3145	43	T-1350	38
3140	32	6130	50	2335	43	2345	37
2345	30	3135	48	6145	42	1095	30
		6135	48	5140	42	52100	30



sluggish and, if cooling is a little too rapid, the structure is sorbitic; if a little too slow, it may be predominantly spheroidized. While little can be done with heat treatment, machinability of these alloy steels can be improved by cold working the ferrite to reduce its ductility. This is particularly true in the low carbon alloy steels like S.A.E. 4615 where free ferrite is the predominant structural element. It has been the experience of some that it is an advantage to cold work the higher alloy steels like S.A.E. 2512 to higher hardness than is usually considered best for free machining, in order to further reduce the ductility. This applies to applications of drilling or broaching where steel cold worked to a Brinell number as high as 250 or even higher may give better results than softer material with high ductility and toughness.

Physical Characteristics

Like other factors affecting machinability, physical characteristics are a part of or are dependent upon a combination of other practices such as manufacture, composition and processing. It follows, therefore, that a discussion of some physical details has been included in the preceding sections. In general the qualities desired, though not clearly defined, appear to be a low order of work hardening capacity with a high degree of work embrittlement, under the conditions of cold work which exist during cutting.

Grain Size — The as-rolled or structural grain size of a steel is separate and distinct from the inherent or austenitic grain size. There is a divergence of opinion about the relationship of structural grain size to machining quality, but it is ordinarily admitted that some improvement in machining performance generally occurs with large grain size. The improvement, however, is not proportional to the degree of coarsening.

It is possible that inherent grain size itself has no direct effect on machinability because inherently fine-grained steels can be structurally coarse. However, fine-grained steels are made with additions of aluminum; accordingly they are generally of poorer machinability because of the abrasive action on the tool of Al_2O_3 present in the steel. There is also the possibility that fine-grained steels will have a fine structural grain unless precautions are taken in hot working.

Hardness — Many investigators have tried to correlate Brinell hardness numbers of steel too closely to machinability, but much of the work has been unsuccessful. This is because composition, structure and mechanical factors are relatively of more importance than hardness. Where Brinell numbers are considered it is generally accepted that a range of about 187 to 217 represents the most desirable.

Tensile Properties — Tensile properties are an index of machinability only so far as they give comparative values of strength and ductility of different steel compositions. Good machining steels are soft and brittle, and have the property of low work hardness. Tensile properties can therefore be used to show the relation of tensile strength to ductility. It is also probable that shearing properties are related to machining properties.

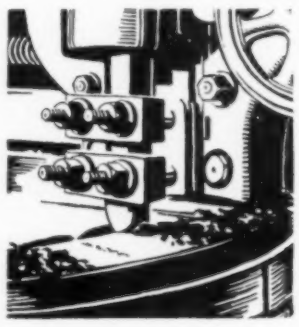
Metallographic Structure — Lamellar pearlite is the most favorable form for carbide to occur in steel for free machining unless there is too much of it, as is the case with very high carbon steels. In such cases the strength is too high for machining, and it is necessary to spheroidize the cementite (or divorce a part of it) as mentioned under thermal treatments. The carbide that is not spheroidized should be in the lamellar form.

Many authorities are of the opinion that nonabrasive inclusions which break up the ferrite particles are strong factors for improved free cutting. Sulphides are an outstanding example of this type. Perhaps the smaller the inclusions the more effective they are. Other factors, such as the molecular and colloidal dispersions in ferrite which are invisible under the microscope, perhaps exert even a greater influence on cutting quality than the few visible ones which inevitably occur.

Classification

Study of the factors influencing the machinability of steel indicates certain groups into which the various steels will fall with more or less predetermined machinability. The various S.A.E. grades have been arranged in the tables printed on the two preceding pages, using S.A.E. 1112 as a basis of comparison with a rating of 100%.

Those S.A.E. grades whose machinability is materially affected by annealing have been rated both "annealed" and "not annealed". The values given are intended only to serve as a guide; adjustments should be made to suit specific operations and conditions. They are for high speed tools in turning, forming, drilling and cutting off operations where a conventional cutting fluid is used. Comments from others will be welcomed.



A case history of a development in modern metallurgy, showing how the density, electrical conductivity, wear resistance, and dimensional accuracy necessary for copper parts in inexpensive self-starter motors were achieved in pressings of electrolytic copper powder, at a cost that is competitive with more conventional methods of forming.

POWDER METALLURGY IN THE ELECTRICAL FIELD

BY CHARLES HARDY, NEW YORK CITY

DURING RECENT YEARS a number of articles have appeared in the technical press dealing with powder metallurgy. It is assumed that the reader is familiar with some applications of this comparatively new art and the advantages of using metal powders in preference to casting, working and machining. This article will, therefore, deal not with the subject in general but with some particular applications in the electrical field.

Powder metallurgy of tungsten, molybdenum and tantalum has been dealt with very fully by other authors, and the applications of these refractory metals in the electrical field are already well known. The metal mainly dealt with in this article is copper powder. Copper as a conductor of electricity has been used universally and its advantages as such need not be stressed here. Copper powder, however, has but comparatively recently been adopted. The steps leading up to its adoption and the results follow:

One of the early applications of copper powder was in the manufacture of "brushes" to lead current into the armature segments of the small electric motors used to start automobile engines ("self starters", so called). A combination of copper and carbon was employed. When electrolytic copper powder became a product of large scale commercial production, the possibility was raised of using this powder for making the brushes. Due to the purity of electrolytic copper and the practical control of the maximum impurities (particularly the oxygen content), the manufacturers of starting motor brushes visualized better results than had been previously obtained with other powders. A condition for its adoption, however, was that the brushes must be able to stand up to 50,000 starts without a break. Tests to prove this required several months but even while these tests were in process the required minimum starts without break were raised to 75,000 (100 a day for two years!) This condition was met and electrolytic copper powder is used for this purpose here, as well as abroad, in large quantities.

Better roads, cheaper cars in the hands of many who use them daily for transportation to and from their work, short week-end trips as well as long vacation trips, demanded a lengthened life of the car. Longer life meant improvement in quality of every part that enters into its manufacture. Hence, every constructional piece became the subject of research. Encouraged by the results obtained with starting motor brushes, the problem of commutator segments was studied. The specifications were quite rigorous:

1. The chemical properties demanded that the copper should show a purity of not less than 99.5% copper. This could readily be met by the copper powder produced electrolytically.

2. The conductivity of the segment must not be less than 96%. This condition offered some difficulty. Metal powders after compression did not at that time have the same density

as the rolled or drawn copper bars from which the segments were cut. It was found, however, that as the face of the copper segment had a greater area than the cross section of the lead-in wire, the specification of 96% could very well be changed. As a matter of fact, during conferences with interested parties it was decided that this standard for conductivity could well be reduced to 65% and still give the results desired. Powder metallurgy, however, could produce material of 90% conductivity and over, and has demonstrated recently with a new technique that 96% conductivity can be insured.

3. A hardness number of 99 or 100 (Brinell test with 10-mm. ball and 500-kg. load) was demanded of the rolled and cut segments, a hardness not then possible by compression of copper powder alone. A further condition required that the segments should have minimum distortion (shrinkage, expansion, warpage). When reheated for one hour at 450° F. the average minimum hardness number should not be below 85 on the above-mentioned scale. A number of tests were run adding other elements such as silver, cadmium, zinc, antimony and various combinations thereof to the copper to obtain the hardening effect. While the results of these tests have since been superseded it might be well to print a table showing the results obtained by Prof. E. Kern of Columbia University, to whom the writer is indebted for his excellent assistance in his work on powder metallurgy.

It will be seen that while results of these preliminary tests on repressing and alloying were far from satisfactory they indicated that additions of other elements to the copper usually hardened it, but the increase in hardness number was not sufficient to compare favorably with the increase due to repressing (equivalent to cold working of the copper).

Further work resulted ultimately in a copper segment which met all the chemical and physical requirements of the specification imposed. The ultimate results are due to the progress made in the other steps of powder metallurgy besides the production of pure powder. Originally, the compression took place in slow working hydraulic presses. Here, the pulsation of the pumps and the entrapping of air were responsible for laminations and bridging in the compacts, for porosity, and for low conductivity. Fast working presses have since been developed. Dies made from tungsten carbide and specially prepared steels, and new ideas as to die construction helped to overcome slipping and adherence of the powder to the sides of the die. Compression in such hard faced dies allowed the production of segments to close tolerances. Re-pressing in similar coining dies produced characteristics of rolled or drawn copper.

One serious difficulty, however, was encountered in drilling the segments to enter the lead-in wire. Segments, which to all intents and purpose were right, occasionally broke the

Hardened Copper Made of —325 Mesh Copper Powder

Dimensions in mm.; Hardness under 10-mm. Brinell ball, and 500-kg. load

Addition	Before Sintering Size	After 1st Sinter		After 1st Repress		After 2nd Sinter		After 2nd Repress		After Reheat 1 hr. at 235° C.*
		Size	Hardness	Size	Hardness	Size	Hardness	Size	Hardness	Hardness
none	30.7 × 17.6	30.3 × 17.3	46	30.7 × 15.8	74	30.7 × 15.7	48	30.7 × 15.3	67	67
1.0% Ag	30.7 × 17.6	30.3 × 17.3	44	30.7 × 15.8	78	30.7 × 15.7	48	30.7 × 15.4	67	70
2.5% Ag	30.7 × 17.6	30.3 × 17.4	44	30.7 × 15.9	78	30.7 × 15.8	50	30.7 × 15.4	70	71
1.0% Cd	30.7 × 17.6	30.5 × 17.3	45	30.7 × 15.9	75	30.7 × 15.8	50	30.7 × 15.4	65	69
2.5% Cd	30.7 × 17.6	30.8 × 17.4	39	30.7 × 16.0	74	30.7 × 16.0	50	30.7 × 15.5	70	69
1.5% Zn	30.7 × 17.6	30.4 × 17.0	47	30.7 × 15.9	74	30.7 × 15.8	56	30.7 × 15.5	70	71
3.0% Zn	30.7 × 17.6	30.4 × 17.5	43	30.7 × 15.9	77	30.7 × 15.9	56	30.7 × 15.6	71	71
1.5% Ag_2Cd_3	30.7 × 17.5	30.9 × 18.1	40	30.7 × 16.3	74	30.9 × 16.6	49	30.7 × 15.9	74	77
3.0% Ag_2Cd_3	30.7 × 17.5	31.1 × 17.9	34	30.7 × 16.0	77	31.5 × 16.6	43	30.7 × 15.7	74	77
1.5% Ag_2Zn_3	30.7 × 17.6	30.5 × 17.5	47	30.7 × 16.0	80	30.7 × 16.0	55	30.7 × 15.7	74	80
3.0% Ag_2Zn_3	30.7 × 17.8	30.5 × 17.8	44	30.7 × 16.0	80	30.7 × 16.0	51	30.7 × 15.7	72	80
1.5% Ag_2Sb	30.7 × 17.7	30.7 × 17.9	45	30.7 × 16.2	80	30.8 × 16.4	50	30.7 × 15.9	71	78
3.0% Ag_2Sb	30.7 × 17.7	30.8 × 18.1	39	30.7 × 16.3	80	31.2 × 16.7	50	30.7 × 16.2	72	80
1.5% Zn_2Sb_2	30.7 × 17.8	30.5 × 17.5	46	30.7 × 16.0	83	30.7 × 16.0	60	30.7 × 15.8	73	80
3.0% Zn_2Sb_2	30.7 × 17.8	30.6 × 17.5	49	30.7 × 16.1	86	30.7 × 16.1	60	30.7 × 15.7	76	80

*Size practically unchanged by this moderate heating.

Commutator Segment in Center Is Punched From Strip With Dull Tools; Others Are Products of Powder Compacts. One at right has integral silver facing

drill, and the hole could not be directed satisfactorily. This trouble was traced to the heat treating practice. As in most laboratories, hydrogen was used in annealing the copper powder before compression and again during the sintering. It was not realized immediately that this caused hydrogen embrittlement of the copper and the subsequent cracking of the segments. Once the use of hydrogen was eliminated and other controlled atmospheres employed for annealing and sintering, the last serious difficulty in producing satisfactory commutator segments was overcome. Not only straight copper commutator segments but also commutator segments with silver facing can now be successfully produced from commercial copper powders.

This article is not to deal with the economics except insofar that the powders are available at a premium over the copper price which compares favorably with the premiums demanded for wedge shaped bars heretofore used, and in which a large scrap loss is experienced, due to wastage from the peculiar shape punched out.

While the production of commutator segments was being discussed with interested parties it was suggested that in view of the favorable results obtained, attempts might be made to produce squirrel cage rotors.

In the past such rotors had been made by several methods, among which are:

1. Die Casting. The resistance ring and rotor bars are die cast in a suitable die machine.

2. Sand Casting. The resistance ring is cast into place after the rotor bars have been assembled in the core iron.

3. Welding, Brazing or Soldering. The resistance ring is held in place by means of welding, brazing or soldering the bars to the resistance ring.

In some of the above methods, especially sand casting, it may be necessary to machine the resistance ring in order to obtain a properly balanced rotor.

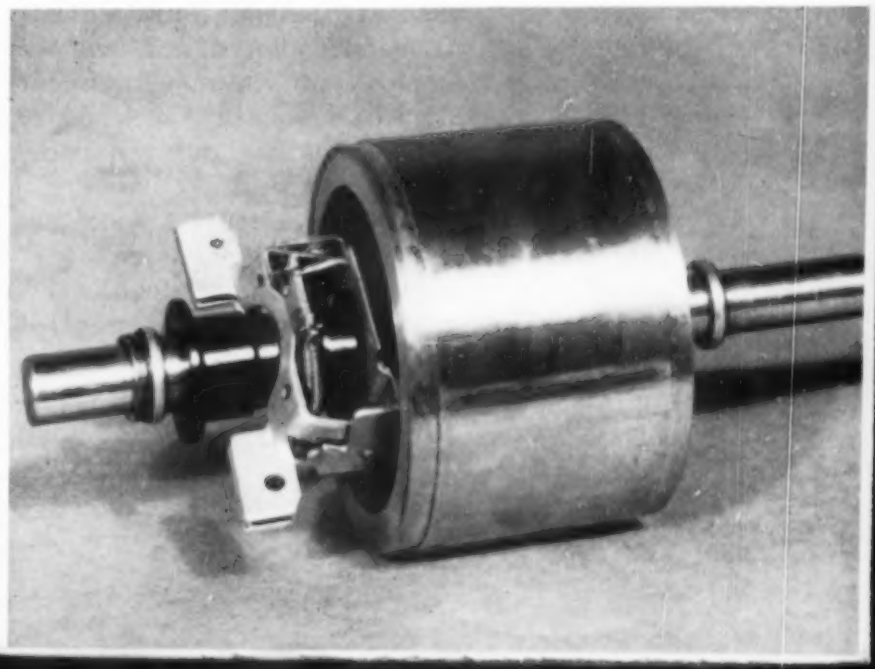
With the metal powder method the rotor bars are assembled in the stacks of core iron punchings, after which the metal powder resistance rings are assembled to both ends of rotor. For this operation a hydraulic press and suitable molds are necessary.

The facilities with which the metal powder could be compressed, and the ease with which the exact weight of the powder for top and bottom of the rotor could be weighed, permitted us to limit the compression to a depth of but ⅛ in., thus saving a lot of copper. The method also assured an even weight distribution and proper balance.

The same procedure and heat treatment employed to obtain the electrical characteristics of commutator segments was followed in the manufacture of the rotor. The rotors were produced in a sufficient quantity, after the initial difficulties had been overcome, and a number were run for a year and longer in the field to prove their superiority. In the laboratory these rotors were subjected to the most severe tests, sufficiently severe to burn out the electric wiring, yet the rotors stood up. The accompanying view shows the rotor of a squirrel cage motor with its synchronization device made with the above described practices.

The writer is indebted for these photographs, and for splendid assistance in applying powder metallurgy to the electrical field, to the Wagner Electric Corp., and particularly to G. A. Waters, chief engineer, and O. Wulfert, mechanical engineer.

Rotor for Squirrel Cage Motor Whose Resistance Rings at Ends Are Pressed From Powder Onto the Assembly



Last winter the Pittsburgh Chapter, ASM, staged an educational course of 12 lectures in Elementary Metallurgy of Carbon and Alloy Steels. Mr. Allison reviewed their metallography in three lectures, and the following is adapted from a portion of his notes. It is an explanation of the now famous "S" curve for plain carbon eutectoid steel, which is reproduced on the Data Sheet, page 65. According to this view the nodules of "primary troostite" are made up of fine pearlite. Likewise a little known acicular constituent will form directly from austenite at subcritical temperatures ranging from about 900 down to 300° F.

GENESIS OF PEARLITE AND MARTENSITE

BY FRANKLIN H. ALLISON, JR.
Metallurgist, United Engineering & Foundry Co., Pittsburgh, Pa.

EVER since equilibrium diagrams have been used by metallurgists, teachers and writers have emphasized that these guide maps apply only to stable conditions — as is of course expressed in the very name, "equilibrium diagram". Only recently, however, has careful note been taken of the *rates* at which the reactions occur in a solid or liquid alloy that is out of equilibrium, in its change over or approach to the stable condition. Since these reactions generally take place in a solid material, a much more substantial amount of time is required than for the reactions between the very mobile molecules in gases or liquids to which we are accustomed in ordinary chemistry.

Thus, a definite amount of time is required for austenite which contains dissolved carbide to transform into well-separated and easily recognizable structures of ferrite and pearlite. If the austenite is cooled through the critical point rapidly, so that the time is not sufficient for these constituents to separate, a much different type of microstructure results. Such faster rates of cooling can easily occur during quenching in water, oil, or air blast.

It has been only in the last few years that the transformation of austenite at fast rates of cooling has been rationally understood. This has been due chiefly to a very important piece of research work by E. C. Bain and E. S. Davenport. A summary of this work on the transformation of austenite in high carbon steel is contained in the data sheet, page 65, reproduced by the kind permission of the Laboratory. The right-hand line on this chart represents the time required for austenite to transform if a small piece of hot steel is suddenly cooled to any temperature indicated on the chart and held at that temperature.

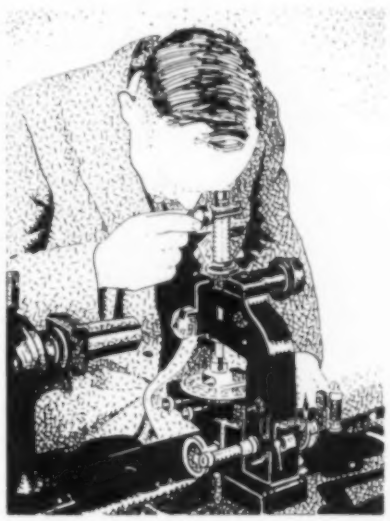
These experiments were made on a 0.78% carbon steel, which would be almost of eutectoid composition. It is to be assumed in the following discussion of individual samples that the steel is first heated above the critical point (or 1340° F. as indicated by the "Ae_1 Temperature" line on the diagram). At higher temperatures the steel is composed entirely of austenite in which the cementite or carbon is thoroughly dissolved. This single-phase structure is shown at the left of the S-curve, just below the center of the diagram.

Formation of Pearlite

If samples of this austenite are suddenly cooled below the critical point to, say, 1250° F. in a lead bath, and held constant at this temperature for various periods of time, and then

quenched in iced brine to fix the structure for examination, it will be found that the austenite will not even *begin* to transform until 20 sec. has elapsed.

Once started, the further transformation is gradual; a further period of time is required until *all* the austenite is transformed, and it is not totally transformed until 200 sec. or 3.3 min. has elapsed. In about one minute 25% of the austenite will have been transformed. If the sample is withdrawn at this time from the hot lead quenching bath at 1250° and quenched in brine, the microstructure will consist of some areas of soft pearlite, but about three quarters of it will be hard martensitic regions which were austenite before quenching, but which transformed to martensite during the brine quench. Similarly, in two minutes about half of the austenite will have been transformed. After 3.3 min. at 1250° F. *all* the austenite will have transformed into pearlite, and there will be no further change in the microstructure on holding the steel sample at 1250° F. for an indefinitely longer time.



What, then, will be the microstructure of this slightly hypo-eutectoid steel which has been transformed completely at a constant temperature of 1250° F.? It will consist almost entirely of pearlite, with a small amount of excess ferrite, and it will have a hardness of about Rockwell C-26.

Examination of the data sheet, page 65, shows that the time required to begin the transformation (the so-called incubation period) and the time to complete the transformation of austenite to pearlite is surprisingly long at temperatures just below the critical, and that these times rapidly shorten as the transformation temperature is lowered. The microstructures and resulting hardnesses of the completely transformed steels show that the pearlite becomes finer and finer — that is, the spacing between laminations becomes smaller — and the hardness increases as the transformation temperature is lowered to 1100° F. (Remember that this discussion applies to plain carbon steel; alloy steels may or may not act in a similar way.) These facts are shown in the tabulation at the right.

The lamellar structure of pearlite is well known, and is shown in the top two micros on the data sheet. Since the austenite (gamma iron) has transformed into ferrite (alpha iron), the carbide which was thoroughly dissolved in the austenite, but is insoluble in ferrite, separates out into thin plates. [It was assumed that these plates favored more or less the planes of the original austenite crystal structure, but the lamellae of pearlite are not as regular and flat as would be expected if this assumption were entirely true. Carpenter and Robertson, two English metallurgists of note, have studied this problem, and in their new book "Metals" conclude that platelets of ferrite and cementite, once started, grow by edge extension, simultaneously, into the austenite.—Editor.]

Let us refer again to the data sheet and note the changes that take place if the metal is rapidly cooled from above the critical point temperature down to 1075° F. and held at this temperature for the austenite to transform.

Primary Troostite

We find that the austenite, now at 1075° F., begins to transform very quickly, in fact in less than a second, which is much earlier than the 20 sec. required at 1250° F. The transformation of all the austenite is completed in about 4 sec., which is also much faster than the 200 required at 1250° F. It will also be observed that the resulting steel is considerably harder, Rockwell C-41 or Brinell 388 as compared with the C-26 resulting from the complete transformation at 1250° F.

The microstructure of this more rapidly transformed austenite will be difficult to resolve except by expert work at very high magnifica-

Transformation to Pearlite

Temperature of Transformation	Time to Start	Time to Complete	Hardness	
			Rockwell	Brinell
1325° F.	35 min.	1 month	C-5	170
1300° F.	5 min.	2 hr.	C-15	201
1225° F.	10 sec.	75 sec.	C-31	293
1150° F.	2 sec.	10 sec.	C-37	352

tion. In the partly transformed specimens (as shown at the left, in the data sheet, at the 1075 level) we see rosettes that apparently radiate fan-wise from nuclei. They are undoubtedly composed of pearlite but the lamellae are much thinner and there are more of them. This structure is known as "fine pearlite" or "primary troostite".

The difference in the manner of separation of the carbide when the transformation occurs at lower and lower temperature is worthy of comment. If the cooling rate is sufficiently slow, so that the reaction may take place at about 1275° F., the transformation of the austenite to ferrite occurs from a relatively few centers and slowly enough for the carbide, which is insoluble in the ferrite, to separate in an orderly manner, much as a crystal of salt would grow in a brine solution by gathering molecules to its surface one by one. On the other hand, if the cooling rate is faster the transformation takes place at lower temperatures, and at these lower temperatures down to about 1000° F. the reaction rate is faster and faster. That is, the austenite transforms so quickly into ferrite that it does not permit the dissolved carbide sufficient time to travel very far, and the separating layers of ferrite and cementite are very fine and radiate from several points at the grain boundary of the austenite crystal, or from some inner nucleus such as an inclusion.

There is no evidence in this work of Bain and Davenport's that any intermediate structure is formed in the transformation of austenite to pearlite; the new crystals of ferrite and cementite simply grow from a supersaturated solution (austenite).

Transformation at 925° F.

If the austenite, in which the carbide is thoroughly dissolved, is quickly cooled from above Ae_1 to 925° F., and held at this temperature for a few seconds, it is observed (and shown in the "S" curve) that the transformation takes place with exceeding rapidity. It begins in a second, and is complete in about 11 sec. This, again, is in sharp contrast to the longer period of time required for the complete transformation at the 1200° F. level. The hardness has now increased to C-42, and the microstructure, as shown clearly on the data sheet, would contain some very fine pearlite in fan-wise radiating groups; lamellae may be too fine for the highest microscopic magnifications. An interesting new constituent now appears, called by various names by various observers. It is the feathery brush shown in the partly transformed specimen at the 925° F. level on the data sheet. It has been given various names by various observers in the past, such as "troosto-martensite", "martensite-troostite", "intermediate structure", "troostite-M", "pseudo-martensite", "quench pearlite", "acicular troostite", "acicular constituent", and "bainite" (the last in honor of Edgar C. Bain, past president ASM, whose work forms the basis of the "S" curve and this discussion). From this variety of names it can be seen that its nature is as yet somewhat problematical, although it is readily distinguishable from true martensite by its etching characteristics, its appearance and its softness.

Acicular Constituent

The "S" curve shows us that as the temperature at which the austenite transforms to ferrite is lowered from 1330 to 1050° F., the change begins sooner and is completed much more quickly. This is what would be expected from what chemists have learned about the crystallization of other solutions (sugar, for instance) and this is what happens down to about 1000° F.

But now a surprising thing happens. If the austenite is cooled quickly to temperatures below 1000° F., the transformation in plain carbon steel begins to take a *longer* time to start and a *longer* time to be completed. Let us look at the transformation if it takes place at 750° F., having been suppressed to this temperature by fast cooling into a salt bath at 750° F. The transformation does not begin until about 8 sec. have elapsed and is not complete until about 2 min. The metal is somewhat harder than after transformation at higher temperature, testing Rockwell C-44 or Brinell 415. Likewise a change occurs in the microstructure. The feathery areas progress in narrow bands across the field of a partly transformed steel, favoring the main planes of the austenite and giving a geometric pattern along three principal directions.

When the steel is wholly transformed at 750° F. the structure is difficult to resolve, as shown in the micros on the data sheet, yet is very definitely different from martensite.

Similar conditions exist in plain carbon steel when the quenching is done in molten salt or oil baths with temperatures down to as low as 350° F. The relations as shown on the

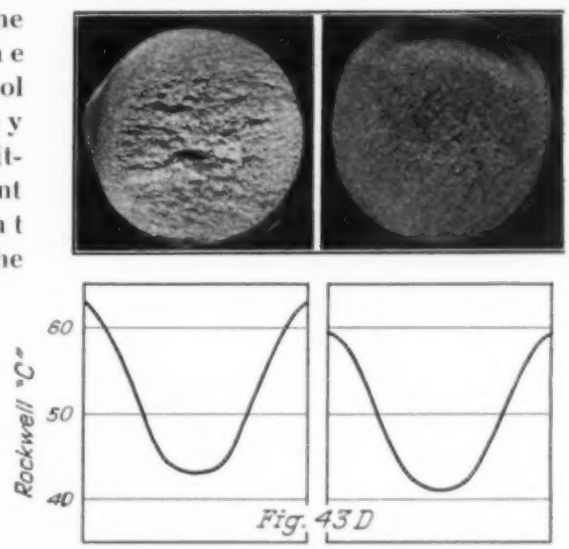
Transformation to Acicular Constituent

Temperature of Transformation	Time to Start	Time to Complete	Hardness	
			Rockwell	Brinell
925° F.	1 sec.	11 sec.	C-42	401
850	2 sec.	30 sec.	C-41	388
750	6 sec.	2 min.	C-44	415
650	35 sec.	8½ min.	C-50	495
550	3½ min.	33 min.	C-56	555
450	5 min.	3 hr.	C-58	578
350	1 min.	4½ days	C-60	601

S-curve may be summarized as shown above.

It should be emphasized that such "isothermal transformation at low sub-critical temperatures" does not occur in practice — that is to say, quenching baths are seldom or never at 300 to 600° F. Even the lead baths used to quench hot wire in the so-called patenting process are 700° F. or higher, and the time the wire is in transit is so short that it is only partially transformed to acicular constituent, and the rest goes to martensite near room temperature.

However, the long time required to complete the transformation at about 350° F. (nearly a *week*) accounts for an interesting fact in heat treatment, which has long been known to blacksmiths in hardening plowshares. Ordinarily, in quenching plowshares in water, there is considerable warpage in the thin blade. But the blacksmiths found that if the shares were taken out of the water while they were still fairly hot, around 300 to 400° F., they could be bent into shape and the warpage kinks straightened out. This bending had to be done immediately, for if the shares were allowed to cool for a few minutes they became glass hard and brittle, and could not be bent without breaking. What happened was that the blacksmiths withdrew the shares from the water at 400° F. before the austenite transformation was complete, in fact, before it even started in the inside of the steel mass. With considerable austenite present, which is soft and ductile, the shares could be easily bent, but after a few minutes the austenite would cool and transform into the hard, brittle martensite and could no longer be deformed without fracture.



Quenched Bars Showing Hard Surface and Unhardened Core, Together With Hardness Variations Edge to Center

Transformation Into Martensite

We now come to the most important action in the hardening of steel, that is, its quenching so rapidly in cold baths that the temperature drops past the 1000° F. region in a second or less, thus preventing any transformation from even starting until the steel cools down to 150° F., more or less, close to the temperature of the quenching bath. Reference to the "S" curve will check the well-known fact that transformation is then very fast, only 10 sec. being required for *complete* transformation at 150° F., and 3 or 4 sec. at 100° F. The resulting acicular microstructure is called martensite. Martensite is composed of a confused needle-like structure with no visible grain boundaries; its units are shaped as long, thin needles. Martensite is extremely hard and brittle and is the principal cause of hardness.

In this structure there is no evidence of a layer-like separation of carbide and ferrite; in fact, it is believed that the carbide may not have come out of solution, so that martensite is sometimes regarded as a supersaturated solution of carbide in ferrite. When austenite transforms to martensite at such a low temperature, the carbon atoms or carbide molecules are no longer as free to move as they formerly were at higher temperatures, and consequently the liberated carbon atoms cannot move far from their original positions. As a result we have the anomaly of a solution of carbon atoms in ferrite, in which it normally is insoluble. This distorts the ferrite lattice tremendously, for ordinarily under equilibrium conditions, the ferrite lattice will not accommodate carbon atoms. This distorted ferrite lattice stucture is called martensite. The distortion of the lattice may be the cause of the great hardness of martensite.

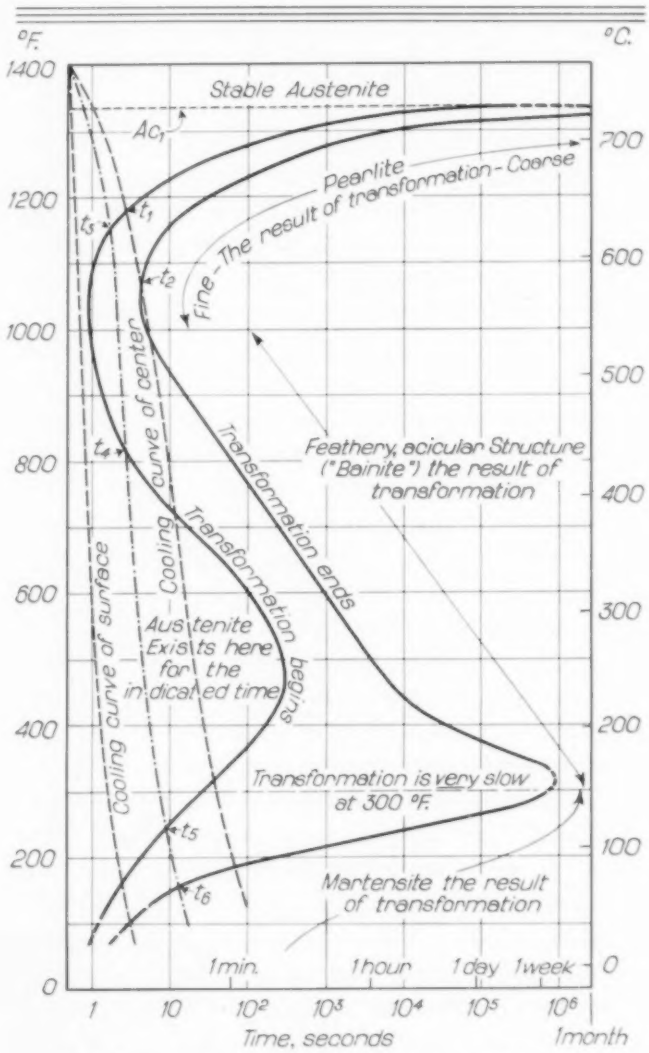
The hardness of a martensitic steel depends to a large extent on the carbon content of the steel. The hardness of quenched steel increases rapidly with the carbon content up to about 0.20% carbon, after which its increase in hardness is more gradual to about 0.55% carbon, whereupon the hardness is slightly affected by larger amounts. The National Bureau of Standards has recently determined the hardness of martensite (the micro-constituent) at about 800 on the Vickers diamond scale, which corresponds to about C-73 on the Rockwell instrument. This is a somewhat higher value than obtainable on the surface of fully hardened carbon or S.A.E. alloy steels (C-66 or C-67 at most); the discrepancy may be due to the fact that quenched high carbon and alloy steels retain a little of the softer austenite untransformed — *complete* transformation of the austenite, as implied by the lettering "Transformation Ends" on the lower part of the "S" curve, does not occur until the steel is tempered.

Microstructure of Quenched Steels

It has been frequently remarked, already, that transformation at constant temperature is a rare thing in practice. It was utilized by Davenport, Bain, and their associates to study the essentials of the operation. In everyday practice a piece of hot steel is immersed in a cold quenching bath. The surface cools very rapidly, the center much more slowly, and intermediate zones will cool at intermediate rates. Transformation conditions and hardness variation, surface to center, are shown in the figure on page 63 from Grossmann's book "Principles of Heat Treatment", and the adjoining sketch.

In the light of our previous discussion the reasons are apparent and the microstructure can be predicted. At the outside is a narrow rim of metal which cooled fast enough to get by at the left of the bend in the curve at 1000°; this zone transformed between 150 and 200° F. into martensite, and its hardness is Rockwell C-60 or better.

Somewhat below the surface, however, the cooling rate is slower, and during passage from t_3 to t_4 part of the austenite is changing to our old friend, primary troostite, or the fan-shaped nodules of fine pearlite. Further reaction stops, however, during cooling between t_4 and t_5; at t_5 (between 200 and 250° F.) the remainder of the austenite transforms to martensite. In this region the boundaries of the austenite grains will have transformed into dark etching nodules (frequently there are also nodules of this type of transformation within the grain). Resulting hardness is a compromise between that of the part transforming at high temperature (say C-42) and that transforming at low (say C-60), depending on the relative amounts of each constituent in the quenched steel.

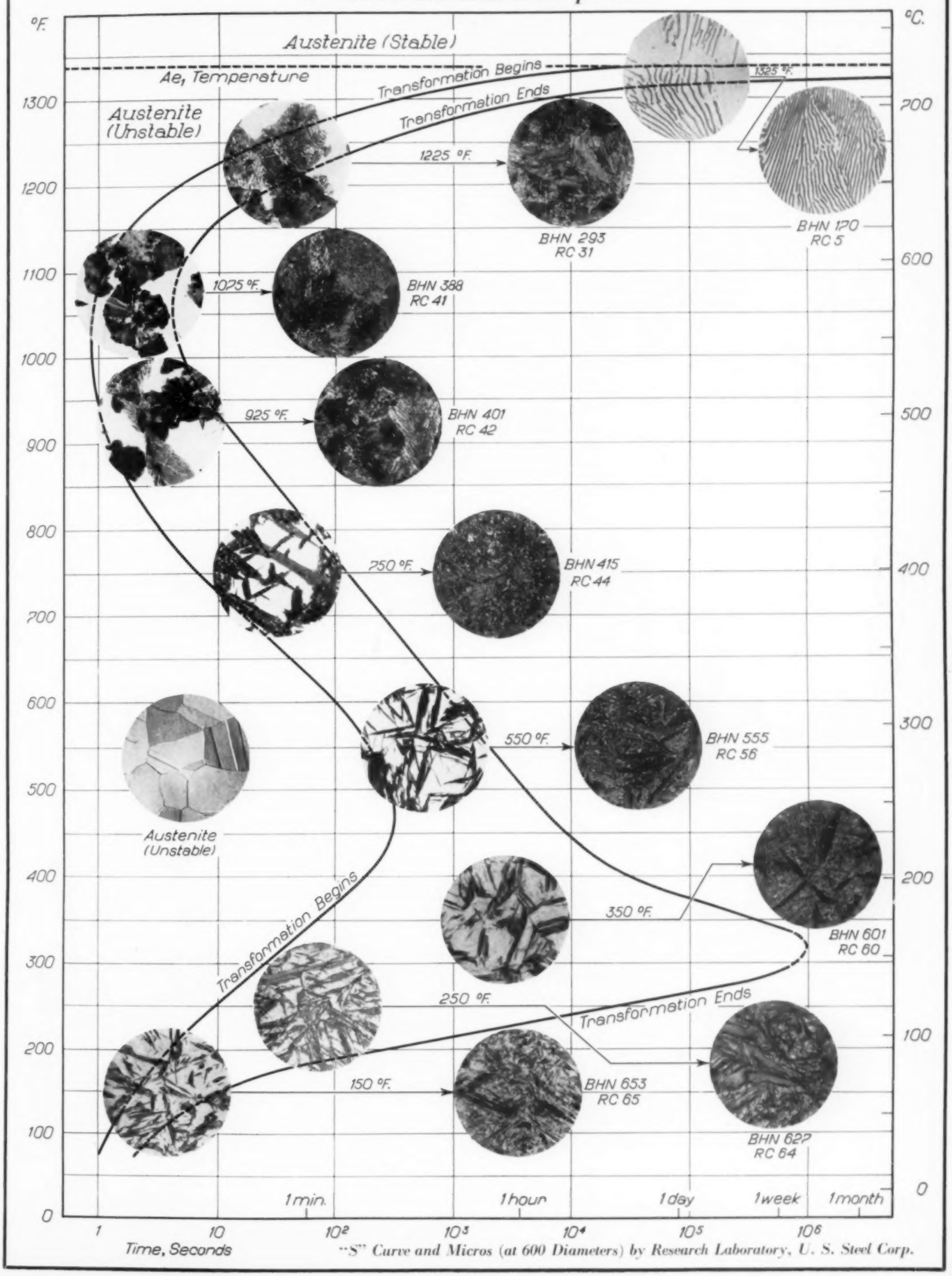


"S" Curve for Eutectoid Steel, on Which Are Sketched Approximate Cooling Curves at Surface, Center and Mid-Radius of a 1-In. Bar of High Carbon Steel, Quenched in Brine

The center of the bar transforms completely between t_1 and t_2 into fine pearlite, with hardness of about C-42. It may be remarked that the microstructure does not need to be completely martensitic to produce the porcelanic fracture ordinarily thought of as representing the "depth of hardening". The transition from brittle porcelanic fracture to more ductile crystalline fracture occurs fairly sharply at microstructures that are about half martensite.

Transformation of Austenite in 0.78% Carbon Steel

at Constant Sub-Critical Temperature



"S" Curve and Micros (at 600 Diameters) by Research Laboratory, U. S. Steel Corp.

. . . *in sub-zero operations*

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THE INTERNATIONAL NICKEL COMPANY, INC., 67 WALL ST., NEW YORK, N. Y.

LETTERS FROM HOME AND ABROAD

Estimation of Inclusions

Paris, France

To the Editor of Metal Progress:

Much has been written on the influence of inclusions in steel. We are often inclined to indulge in generalizations, extrapolations, and premature or exaggerated hypotheses, considering the problem only in the light of our present limited knowledge of steel making, and of chemical, micrographic or other investigations.

In order to get a clear idea of what can take place, omitting the minimum of possible factors, it should be recalled that inclusions are complex constituents existing in minute proportion and in a very finely divided state in comparison to the ordinary constituents of alloys, either visible or invisible. In transposing to a minute scale the known facts regarding such constituents, a conception of the whole may be acquired which omits certain factors or modes of action, without which the conception cannot be considered to be complete.

In general, the effect of any constituent depends upon the following factors:

1. Morphological factors — shape, size and dimensions, and distribution.

2. Specific factors — nature and properties in relation to those of the metal, and their proportion in the metal.

3. Indirect or inferred factors — influence on the surrounding metal.

The morphological factors are placed first because the least practical knowledge exists concerning their importance and mode of action, yet they often play a preponderant role.

It is known that the effect of graphite on the malleability of cast iron is entirely different, depending upon whether the graphite solidifies as flakes, or as more or less rounded nodules; likewise, the deleterious effect on the tensile strength and elongation will depend, in either case, upon the size and proportion of the flakes or nodules.

Similarly, films of inclusions, either visible or invisible, may have a considerable influence on certain mechanical properties, notably ductility and path of rupture (whether across or between the grains), as well as on recrystallization and grain growth phenomena; this is in accordance with Tammann's conceptions of substances trapped between the primary crystals of solidification. (It must not be forgotten that two metallic surfaces will adhere only when there is optical contact, that is, when the space between them does not exceed the visible wave length — 0.0001 mm.) As we noted many years ago in *Revue de Métallurgie*, vol. XII (1915) p. 155, this influence may persist through various heat treatments. To break up or transform this often invisible network into disseminated particles, it is necessary to resort to forging, or to the coalescence of the inclusions through their solubility in the metal at high temperature, or their coalescence by the addition of elements which modify the nature of the inclusion.

As discussed in the January issue of Metal Progress, page 68, certain additions (manganese and aluminum in steel, manganese in nickel) modify the shape, the number and the distribution of inclusions. This is a consequence of a change in the nature of the inclusion and is therefore an indirect effect.

The direct effect of the chemical nature of the inclusion has not yet been effectively observed and proven except in some special properties, as, for example, surface properties such as polish and corrosion.

It must not be forgotten that since inclusions are tightly encased in the plastic mass of the surrounding metal, their mechanical properties and particularly the brittleness of the inclusions may be modified. Therefore, although the degree of fineness and the number of inclusions may, in principle, affect the mechanical properties, comparison should be made only under similar conditions of shape, distribution and nature of the inclusions. This is a fundamental requirement for the accuracy of those inspection methods in which the proportion of visible inclusions on a polished section is counted in categories according to their size (or length if observations are made in the direction of forging). However, the relationship between this physical purity and mechanical properties is far from being accurately known, and this is, after all, the important thing in practice.

On the other hand, blowholes (gaseous inclusions) and interdendritic pipe in steel castings (METAL PROGRESS, August 1938, p. 152) can best be estimated and revealed by a study of the mechanical properties, particularly the elongation, reduction of area and impact strength; this is much more sensitive than a visual examination and a determination of the density.

In our opinion, one of the best methods of estimating quality of structural steels is the determination of mechanical properties after suitable heat treatment (associating either tensile strength and reduction of area, or hardness and impact strength). Tests should be made under conditions in which inclusions have the maximum effect — that is, transversely. Micrographic estimation can be used as an explanatory complement or as a means of information when it is impossible to determine the above-mentioned mechanical characteristics.

It is highly recommended, in view of the uncertain and subjective character of this method of estimation, to include a group of inspection methods, such as chemical analysis of impurities, grain size, and normality.

While this transverse tensile test (or general mechanical tests) is entirely appropriate to determine the effect of very small inclusions uniformly distributed, and thus to judge the quality of the steel, large inclusions generally escape these methods, since they are only revealed if they are present in the tensile test piece or even in the zone of rupture. Yet their influence is considerable; as shown 20 years ago in *Revue de Métallurgie*, vol. XVI, p. 340, they become the origin of transverse fractures accompanied by very poor mechanical characteristics. It is therefore quite important to determine the *presence* of these large inclusions which the tensile test rarely reveals.

Micrographic investigation, on condition that it is made over the total thickness of the ingot, from center to periphery (see Perrin, *Iron Age*, vol. CXL, p. 123, 1937) and if necessary at three different levels in the ingot, may give the necessary information if attention is paid not so much to the number, but to the average size of inclusions; if those observed are small, the probability of encountering large inclusions is slight.

A more extended investigation may give direct information on the *frequency* of large inclusions. Preferably three cuts should be made in a lathe or milling machine, and each surface carefully explored.

The influence of inclusions on mechanical properties is more difficult to define if they modify the surrounding metal so that the latter may be different in nature, purity and structure from the main metallic mass. Although this relationship may only be a concordance of position, as between sulphurous inclusions and zones of dendritic segregation, there is sometimes a relation of cause to effect — in other words, a direct action of the inclusion. Thus, inclusions may sometimes act as a decarburizing influence, or centers of crystallization during solidification or transformation, and the principal effect of the inclusion may depend upon a shell of fine-grained metal, or of pro-eutectoid ferrite, or even a troostitic or pearlitic structure.

It is entirely conceivable that the same inclusion may facilitate thermal regeneration or impede superheating, depending upon whether it takes the form of finely dispersed particles or of a network of fine films. This action depends on the temperature and the solubility of the inclusion in the surrounding medium.

In conclusion, the following considerations should be borne in mind:

1. The manufacture of steel, particularly its final history, is so closely related to the formation and evolution of inclusions that the study of the latter may furnish valuable information on the steel making process.

2. The steel making process, moveover, has generally a close connection with the properties and quality of the steel. This community

of origin does not necessarily establish a relationship of cause and effect between inclusions and quality. Such relationship must be directly proved in every case.

3. The effect of small inclusions may be either favorable or unfavorable and consequently it is best at present to make no definite statement. Large inclusions, on the other hand, seem to have a more definite and significant effect.

4. In short, estimation of the effect of inclusions may be based on the *number* of inclusions or defects exceeding a certain dimension, and substantiated by a combination of three tests: *(a)* Exploration of three contiguous surfaces, *(b)* micrographic examination, *(c)* transverse mechanical tests, comparing groups of two characteristics such as tensile strength and reduction of area, or hardness and impact strength after a definite heat treatment.

ALBERT PORTEVIN
Professor, Ecole Central des Arts et Manufactures

THREE LETTERS ABOUT NAMES FOR HARDENABILITY TEST

PHILLIPSBURG, N. J.

To the Editor of METAL PROGRESS:

It was about ten or twelve years ago that FRANK SHEPHERD of our organization first introduced the so-called SHEPHERD test, or hardenability test. The penetration-of-hardness and fracture-grain-size test or "P-F test" came later; it was described at the last Metal Congress held in New York, which you will find was in 1934. The characteristics of metals for which these tests were designed were firstly the "hardenability", a term we have always applied to *depth* of hardness penetration, and secondly the "body", or the tendency to coarsen at elevated temperatures.

Problems of manufacture at Ingersoll-Rand Co. are such that we are far more interested in the depth to which water hardening steels will harden than we are in the actual degree of hardness obtained, for it is generally found that water hardening steels of a given composition usually produce the same degree of hardness but not always the same depth under identical conditions.

We have watched with interest the various attempts to develop new hardenability test methods, and have watched the developments of the old SHEPHERD test for hardenability, and so far nothing has appeared quite as useful for our purpose as the latter.

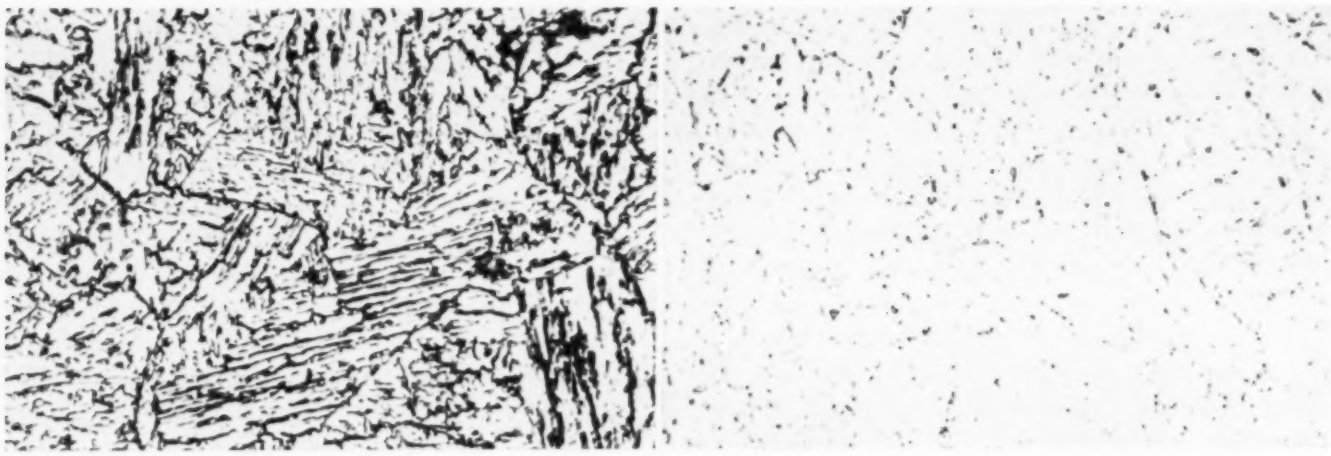
The more satisfying of all our tests, which are made to cover the consumption of approximately 2500 tons of high carbon toolsteel in a year, are those tests where we manufacture a dummy article, practically identical with the product to be made from the steel in question, use a standard heat treatment and then section the specimen in such a manner that the reaction of the test material to the required heat treatment is at once obvious. A simple correlation between these practical tests and some of the purely laboratory tests may save some time. However, when manufacturing facilities are well organized, and the final product not too large nor expensive, then the safest thing is the semi-finished dummy part which tells at a glance the entire story and needs no conversion factors. We favor that sort of thing and see nothing but trouble in unwilling compromise before there is achieved a standard method to determine the metal characteristic now called somewhat loosely "hardenability".

H. L. DAY
Metallurgist, Ingersoll-Rand Co.

PEORIA, ILL.

In reviewing the item on hardenability in "Critical Points" in the May issue, I find that the paragraph designated by the figure 3 does not exactly coincide with the use we make of the completely quenched specimen. In this respect we have taken issue, as indicated by F. F. VAUGHN's discussion of BURNS, MOORE and ARCHER's paper in the *Transactions*.

In the hardening of S.A.E. 1045 steel, for example a crankshaft, we are much more interested in what happens within the first ¼ in. of depth of hardening than we are in the average hardness, or the hardness denoted as the "S-A-C" rating. If we were machining $\frac{3}{16}$ in. from the radius of a crankshaft after it had been hardened and tempered to 269 Brinell number, but only $\frac{3}{16}$ in. depth from the surface was at this hardness intensity, then our labors would have been expended in vain. In other words, we have paid a high price for removing the very layer of hardness which we would like to have preserved on the ground diameter of the crank journal. The *slope* of the hardness penetration curve from ⅛ to ¼ in. below the surface of the 1-in. diameter bar is therefore the gage which we apply to much of the steel of this analysis which we consume in various parts.



Etched in 2% nital — Etched in hot sodium picrate

S.A.E. 3312, Heated at 1650° F., Transformed in Molten Salt at 700° F. for 60 Min. Rockwell hardness number C-34. Magnified 1000 diameters

In regard to the last paragraph, I personally like the expressions "end-quench hardness penetration" and "section-quench hardness penetration".

G. C. RIEGEL
Chief Metallurgist, Caterpillar Tractor Co.

CHICAGO, ILL.

I am led to suggest a little modification in the thought contained in your "Critical Point" on names for the hardenability test.

It seems to me that the whole problem in hardenability testing is to find out how the degree of hardening changes as the cooling is slowed down. In immersion hardening, the cooling becomes slower as one proceeds toward the interior of the bar, so that one may use the familiar U-curve of hardness plotted against distance from the axis. In steels of low hardenability a 1-in. round may be employed, as in the BURNS, MOORE and ARCHER test. For steels of higher hardenability, as for alloy steels, considerably larger sizes or a number of sizes are desirable, as in the studies being currently carried out at Battelle Memorial Institute in Columbus, Ohio.

In the end-hardening employed by JOMINY (a very excellent test) the slower cooling is encountered as one proceeds away from the quenched end.

It seems to me that this viewpoint of the relation of hardness to rate of cooling is a useful one to point out, since it not only involves the true hardenability of the steel itself but also by inference brings in the effect of quenching medium.

MARCUS A. GROSSMANN
Director of Research, Carnegie-Illinois Steel Corp.

MATHEWSITE

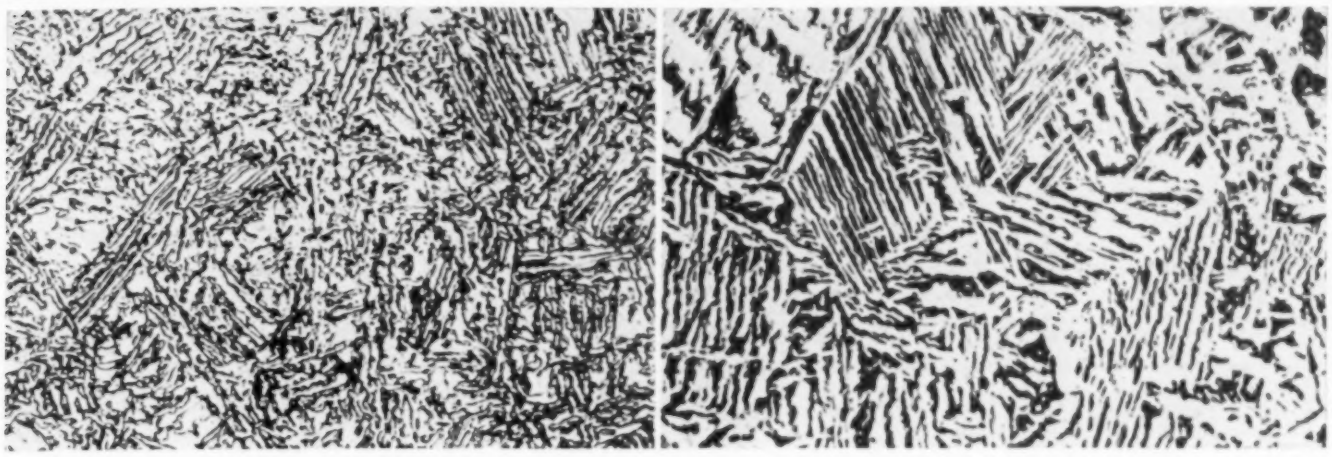
(PSEUDO-MARTENSITE IN ALLOY STEEL)

HARRISON, N. J.

To the Editor of METAL PROGRESS:

In the May issue you refer on page 486 tc the name "pseudo-martensite", and then, with the support of EDGAR BAIN, you conclude that the structure given that name might properly be called "bainite", since it is a product of transformation which formed at a low temperature, but at a temperature probably higher than 200° F. I am of the large number of his contemporaries who hold Doctor BAIN in great esteem, and I believe it fitting and proper that a microstructure, the discovery of which was due to his keen observation, should be named after him.

In our work at the research laboratory of Crucible Steel Co. of America on transformation-temperature-time curves, (we call them "TTT curves" or "triple T curves" because many of them are quite different in shape from BAIN's original "S" curve for carbon steel) we have found transformation products at temperatures between about 1300 and 300° F. which are different from pearlite and bainite. I think it would be rather confusing to give *all* these different products the same name. I suggest that the dark etching, feathery, or zig-zag structure, which has so beautifully been photographed by VILELLA, retain the name bainite. Unfortunately, in the alloy steels, it is frequently difficult, as shown in the paper by PAYSON and HODAPP in the April issue of METAL PROGRESS, to distinguish between bainite and



Etched in 2% nital — Etched in hot sodium picrate

S.A.E. 9255, Heated at 1700° F., Transformed in Lead Bath at 800° F. for 5 Min. Rockwell hardness number C-32. Magnified 1000 diameters

sorbite. However, this difficulty may be eradicated in the course of time by improvements in etching technique.

I submit herewith some photographs of structures, formed by transformation at intermediate temperatures, which do not look like bainite, and which I believe should have a name other than bainite. These represent a silico-manganese steel (regular S.A.E. 9255) heated to 1700° F. and transformed at 800° F., and a chromium-nickel steel (regular S.A.E. 3312) heated to 1650° F. and transformed at 700° F. These structures are similar to each other but different from bainite in that they do not etch dark. They are, in fact, structures which might well have been called "pseudo-martensite". I propose the name "mathewsite" for this type of structure, in honor of the late JOHN ALEXANDER MATHEWS, an American pioneer in alloy steel development, and an honorary member of the ⊜. Doctor MATHEWS guided the research work in this company for many years, and his name should be an inspiration to all metallurgists.

It is with some degree of hesitation that I suggest the following tentative definitions (or descriptions) of the structures mentioned:

Martensite: A structure that appears light in color after a relatively short etch in 2% nital. With a heavier etch it shows acicular markings. It is relatively unaffected by a hot sodium picrate etch.

Mathewsite: A structure that appears light in color after a relatively short etch in 2% nital and shows markings in a somewhat Widmanstätten pattern. Carbides in this structure are readily shown by a hot sodium picrate etch.

Bainite: A structure that appears dark in color after a relatively short etch in 2% nital, and shows feathery or zig-zag markings.

Sorbite: A structure that appears dark in color after a relatively short etch in 2% nital and shows very little, if any, line or plate pattern.

PETER PAYSON
Research Laboratory
Crucible Steel Co. of America

COMMERCIAL IRON OF HIGH PURITY

TURIN, ITALY

To the Editor of METAL PROGRESS:

The fact is well known that the peculiar and useful properties of technically pure iron are greatly and suddenly improved when the remaining impurities contained in it are reduced below certain very low limits. In fact, some of the properties — like the plasticity at ordinary temperatures and the magnetic properties — undergo so great a change that iron of high purity behaves in some respects like a new metal, suitable for applications for which the commercially pure iron is inapplicable.

Unfortunately the processes now known (like, for instance, the carbonyl process) for obtaining iron of such high purity are very expensive, so that the practical application of this useful metal is limited to very special purposes. It is important, therefore, that a new process has been recently developed and patented by Mr. ARATA of Rome for the economical production, on a tonnage scale, of iron of a purity greatly exceeding that of all known commercial irons, and reaching the limits where the peculiar properties of chemically pure iron are

well developed. Given the conditions prevailing in Italy as to relative costs of coal and electric power, the process is now applied as follows:

Fine iron ores — like iron sand, calcined pyrites, residuals of the chemical treatment of bauxite — are smelted in an electric furnace with proper reducing agents and fluxes. When the reduction is complete (which usually requires the formation and skimming of one or two slags, according to the composition of the ore) the iron bath should contain a small excess of the reducing agents — for instance, 2% silicon when ferrosilicon is used with the reducing agents. The essential feature of the new process lies in the exact and complete elimination of these residual reducing agents, without the slightest oxidation of the metal bath.

It is evident that the technical conditions of the first, or reducing phase, of the Arata process may be altered in order to suit technical and economic conditions different from those prevailing in Italy, where steel scrap is scarce, coal comparatively expensive, and hydro-electric power cheap.

The cost of the new product, under present local Italian conditions, is approximately 80% above that of the best normal low carbon electric steel.

In its chemical purity and physical and mechanical properties, the Arata iron compares favorably with the best pure iron obtained so far in the laboratory or by expensive industrial processes such as the Fischer process.

A typical analysis of the metal is the following: Carbon 0.008%, manganese nil, silicon 0.005%, phosphorus 0.002%, sulphur 0.01%, nickel, titanium, aluminum and chromium nil, iron 99.97%.

Heat treatment of the forged samples mentioned in the table includes reheating to 1650° F., quenching from 1475° F., and reheating to 1475° F., followed by slow cooling.

The new product shows much more clearly the well-known high apparent hardness number typical of electrolytic iron which usually reaches 60 to 70 Brinell for a tensile strength not exceeding 45,000 psi. This apparent hardness is due to the effect of cold working under the indentor during the test. The Arata iron reaches 95 to 105 Brinell. Test pieces reduced by cold forging to 25% of their original thickness give Brinell hardnesses exceeding 200. The practical importance of this property is obvious, especially for deep drawn pieces.

Average Physical Properties of Arata Iron

	Forged	Forged and Heat Treated
Yield point, psi.	17,000 to 21,000	14,000 to 18,500
Tensile strength, psi.	40,000 to 42,500	38,000 to 41,000
Elongation on 5 diameters	40 to 45%	50 to 55%
Reduction of area	65 to 70%	75 to 80%

Magnetic and electric properties correspond fully to those of the purest iron produced in any other than expensive chemical or laboratory processes. Given the much lower cost of this new product, the importance of this fact is obvious.

Resistance to the action of many chemical agents is very high, and this forms another important property of the new product.

The Arata iron has been already produced in large quantities and tested on large industrial scale for many applications. In the manufacture of deep drawn pieces it is being cold worked in place of copper or brass, without any change in machinery — or in tools, except that the number of operations necessary for obtaining a given piece may be reduced.

Federico Giolitti
Consulting Engineer

Are Large Amounts of Radium More Effective Than Small?

Anacostia, Washington, D. C.

To the Editor of Metal Progress:

In the April issue of Metal Progress (page 382) H. R. Isenburger describes the radiography of very thick steel sections by means of gamma rays, wherein he says that a piece of cast steel 9.5 in. thick "thought to be a record" was radiographed in five days with 500 mg. at a 15-in. source-to-film distance. This time, it was stated, is less than one third of the time recommended in the technique developed at the U. S. Naval Research Laboratory.

In the initial development work of Mehl, Doan and Barrett, published in *Transactions*, A.S.S.T., volume 18 (1930), page 1192, may be found radiographs of heavy sections of 8, 10 and 12 in., taken with radon sources equivalent to 2100 mg. of radium, in times around 10.5 hr.

The technique subsequently developed is based on a satisfactory film density of 1.6 units on the H.&D. scale for a single film. Under the experimental conditions mentioned, the necessary exposure time, according to the Navy Chart, is about 330 hr. By employing double viewing, however, only 0.6 of this time, 198 hr., or 8 days, is required, which is less than twice the time said by Mr. ISENBURGER to be correct according to his book "Industrial Radiography". This book was consulted and it was found, by extrapolating his chart to 9.5 in., that an exposure of about 75,000 millicurie-hours or 150 hr. with 500 mg. would be required. This is a time coming closer to 6¼ days than 5 days. Furthermore, his chart is based on a time required to give a density of 0.7 unit, and using two films between three lead intensifying screens of 0.005 in. thickness (not 0.06 in. as mentioned in the letter — doubtless a slip of the typewriter or the printer). Whether single or double viewing is employed is not stated in the letter.

Furthermore, it is stated that the film was developed at a temperature above 70° F. for a time of 10 min., while standard practice calls for 8 min. at 70° F. in fresh developer. If the writer used fresh developer, it is possible that additional density, contributing nothing to the quality of the negative, has been gained by chemical fogging.

It is mentioned that a $\frac{3}{16}$-in. thick penetrameter on the source side of the test piece failed to show, and thus no information is given about the possible sizes of defects that may be revealed in this rapid technique.

While the letter says that an area of 10-in. diameter on the casting is covered, it is not stated whether this is on the front or back. A simple pencil construction will show that if this area is on the front the outermost rays will have to travel through 20 in. of steel; if it is on the back, the frontal area of the casting viewed is in a circle of 3.66 in. diameter. Defects outside this circle on the front will be missed.

Finally, but most important, is Mr. ISENBURGER's implication that large amounts of radium are somehow more effective than small amounts used for proportionately longer times. Since the strength of a source of radiation is measured by the energy flux per unit area normal to the direction of propagation at some arbitrary point, this implies that the well-known photographic "reciprocity law" is not valid for gamma rays. In all work carried out at the Naval Research Laboratory, using only lead intensifying screens, it has always been found that the required exposure time varies inversely as the strength of the source.

With increasing thickness of section, radiographs made even with standard photographic technique are none too good, due to the increasing effect of scattered and secondary radiation. Any real advance in the radiography of thick steel sections must include means of removing or reducing the effects of secondary and scattered radiation.

HERMAN F. KAISER
Division of Physical Metallurgy
Naval Research Laboratory

MR. ISENBURGER'S REPLY

Mr. KAISER seems to agree with my conclusion that this work is very difficult and needs considerable research before it can be done on a reliable and satisfactory basis. He has also drawn attention to an omission and the error in thickness of the lead X-ray foils. I should have mentioned that this was the first attempt to radiograph such a great thickness of steel in actual field work, whereas the original research by Doctor MEHL and his associates was done under laboratory control and facilities.

As far as the exposure charts are concerned, I regret that I cannot agree with Mr. KAISER. I extended our charts and found approximately 60,000 millicurie-hours, the time which I actually used. The exposure time in accordance with the Naval Exposure Dial was given to me over the telephone. While we exposed two films, only one was used in reading the gammagraph.

When the first films were processed under standard technique, the negatives were too faint to amount to anything at all. We then added potassium iodide and warmed up the developer, which was not exactly fresh any more. The result was a fair negative which showed the hole in the 2% marker facing the film. This last statement was made to show that we cannot depend on anything but the conditions through the section of the casting facing the photographic film.

With respect to Mr. KAISER's last paragraph, we may mention that we have developed certain filters which will eliminate most of the secondary and scattered radiation.

HERBERT R. ISENBURGER
President, St. John X-Ray Service, Inc.
Long Island City, N. Y.

PERSONALS

J. M. Brownback ⊜ received his degree of metallurgical engineer from University of Illinois on June 12 and is now with the Mueller Co., Decatur, Ill.

Richard Rimbach ⊜ has been appointed technical advisor to R. C. Enos, president of Standard Steel Spring Co., Coraopolis, Pa.

Transferred: **Jack C. Ranney** ⊜, from the cold roll laboratory, Cuyahoga Works, American Steel & Wire Co., Cleveland, to New York as commentator at the U.S. Steel Subsidiaries Exhibit at the World's Fair.

T. H. Sanderson ⊜, formerly contact representative of the metallurgical division at Chicago, has been made assistant to superintendent, rail mill, Gary Works of Carnegie-Illinois Steel Corp.

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Watch For "STUART OILS" In Operation At Cleveland Machine Tool Show

T. F. Schilling ⊜, president of Manufacturers and Fabricators, Inc., Cleveland, announces the removal of their offices and plant to new and larger quarters at Elyria, Ohio.

Appointed general superintendent, Babcock & Wilcox Tube Co., Beaver Falls, Pa.: **Luke E. Sawyer,** formerly assistant general superintendent.

Henry A. Weyer, engineer, formerly with Nazel Engineering & Machine Works of Philadelphia, is now with Chambersburg Engineering Co., Philadelphia.

Vincent H. Godfrey has joined the general sales staff of the Page Steel and Wire Division of American Chain & Cable Co., Inc., Monessen, Pa.

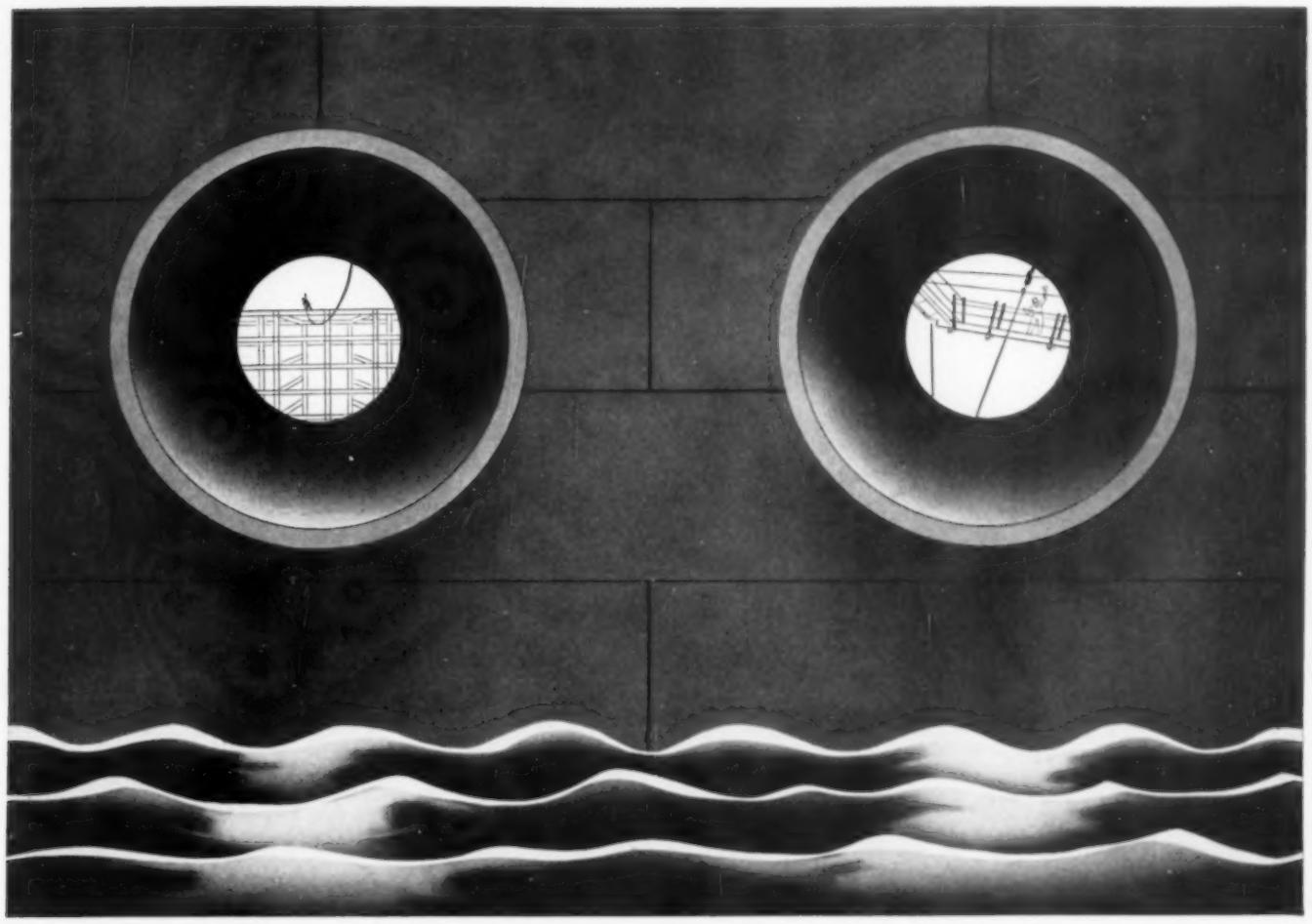
Awarded the Edward Longstreth medal of the Franklin Institute for his discovery of electrolytic color plating: **Jesse E. Stareck,** research laboratories, United Chromium, Inc., Waterbury, Conn.

Honored by a dinner and plaque for 50 years continuous service with Revere Copper and Brass, Inc.: **Clarence S. Parker,** now serving in an advisory capacity to the mill at Taunton, Mass.

G. W. Higgens ⊜ is now employed by the National Malleable & Steel Castings Co., at the Chicago plant.

Robert G. N. Evans ⊜, for many years engineer in charge of research for Bunting Brass & Bronze Co., has removed to Milwaukee and established himself as consultant on lubrication and bearing problems.

Made district sales manager of the New England territory, Allegheny Ludlum Steel Corp.: **W. L. Weaver** ⊜, formerly special representative in Watervliet, N. Y. **J. F. Dolan, Jr.** ⊜ has been made assistant district sales manager in New England.



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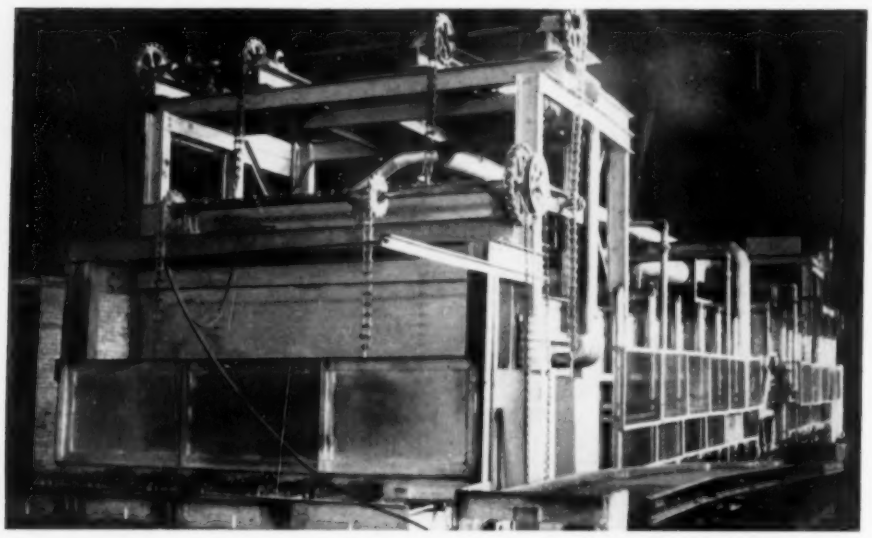
PERSONALS

Walter P. Wallace of Columbia Steel Co. is research attendant at the U.S. Steel Exhibit, Golden Gate International Exposition in San Francisco.

F. W. Patterson has severed his connection with the Small Arms Factory, Wales, Australia, and is now in consulting practice.

Samuel L. Hoyt, trustee, formerly director of metallurgical research with A. O. Smith Corp., has joined the staff of Battelle Memorial Institute as technical advisor in the planning and conduct of metallurgical research.

George L. Kehl, assistant professor of metallurgy, Lehigh University, will be associated with the United States Steel Corp. Research Laboratories at Kearny, N. J., after August 1.



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Selected to deliver the Edgar Marburg lecture of the American Society for Testing Materials: **Herbert Fisher Moore**, research professor of engineering materials, University of Illinois.

Wm. M. Kahlbaum, formerly assistant superintendent, the Midvale Co., is now metallurgist at Watervliet Arsenal.

Charles Lee Clayton of the wire and nail mill of Columbia Steel Co., Pittsburg, Calif., has been transferred to the United States Steel Exhibit at the Golden Gate International Exposition.

Charles J. McCarthy, formerly assistant general manager of Chance Vought Aircraft Division, is now assistant general manager of the newly merged Vought-Sikorsky Aircraft Division of United Aircraft Corp.

Glen R. Ingles, on leave of absence to study metallurgy at University of Illinois, will return to the metallurgical laboratory of Reed Roller Bit Co. in Houston, Texas, for the summer.

J. A. Rutherglen, mechanical engineering graduate from Oregon State College, is entering the service department of the Electro-Motive Corp., General Motors subsidiary in La Grange, Ill.

Ashland Henderson, University of Cincinnati, is metallurgist with the Standard Division of Frigidaire Division of General Motors Corp., in Dayton, Ohio.

C. W. Gisner, formerly plant engineer, R.C.A., Camden, N. J., is now tool engineer on steam turbines and steam turbine generators at General Electric Co. in Schenectady.

Selected to receive the Edward Goodrich Acheson gold medal of the American Electrochemical Society: **Francis C. Frary**, director of research of Aluminum Co. of America.

Retired: **Fred T. Llewellyn**, as research engineer for United States Steel Corp.

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Bethlehem Comokut is essentially an 18-4-1 steel with approximately 5 per cent cobalt. The latter element increases its ability to retain hardness at red heat so that deeper cuts at higher speeds can be maintained, making it definitely superior to 18-4-1 on heavy roughing cuts.

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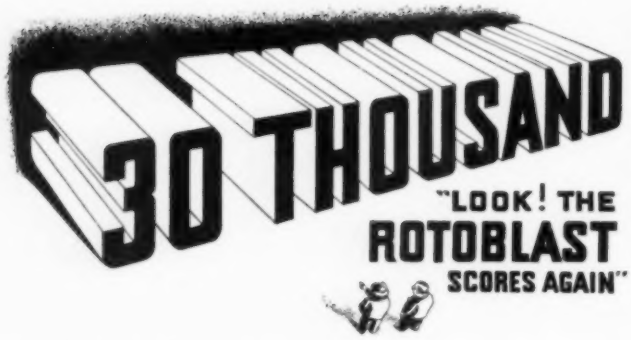
For complete information about these and all other grades of Bethlehem tool steels, telephone or write the Bethlehem district office near you or direct to Bethlehem Steel Company, Bethlehem, Pa.

BETHLEHEM STEEL

BETHLEHEM STEEL COMPANY



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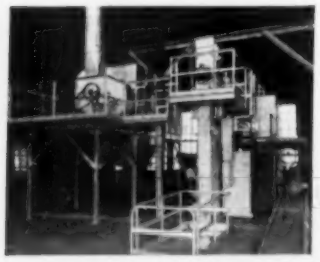

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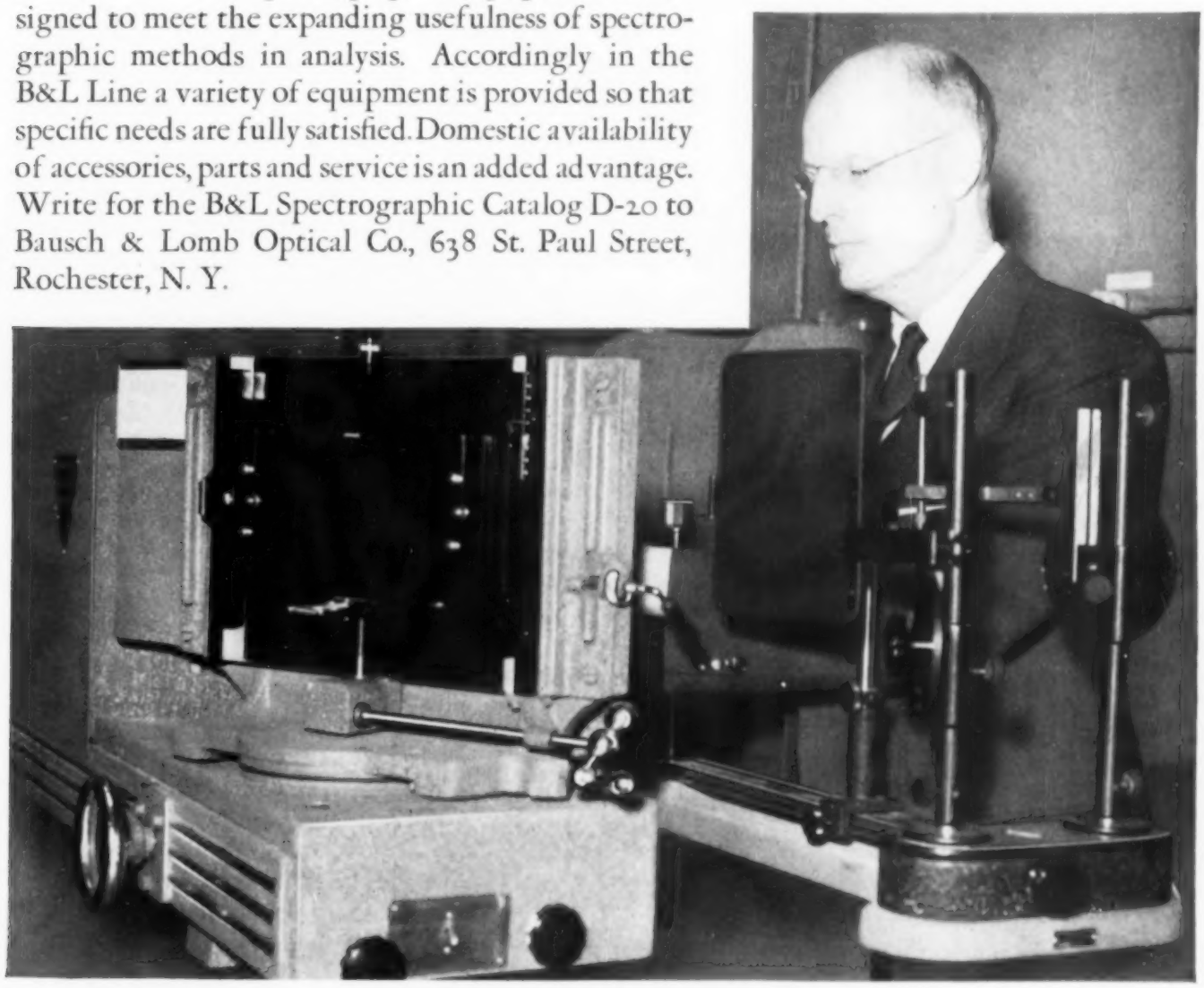

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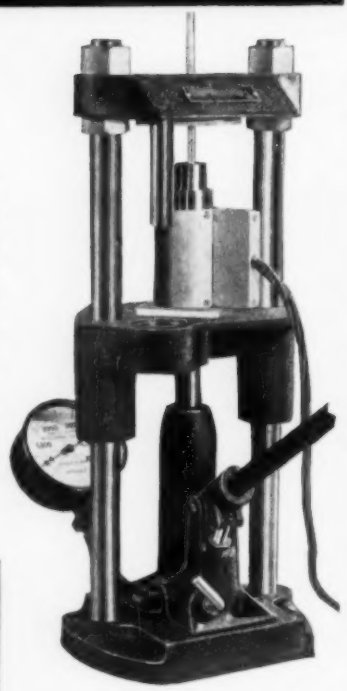

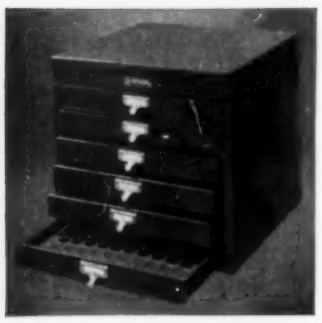

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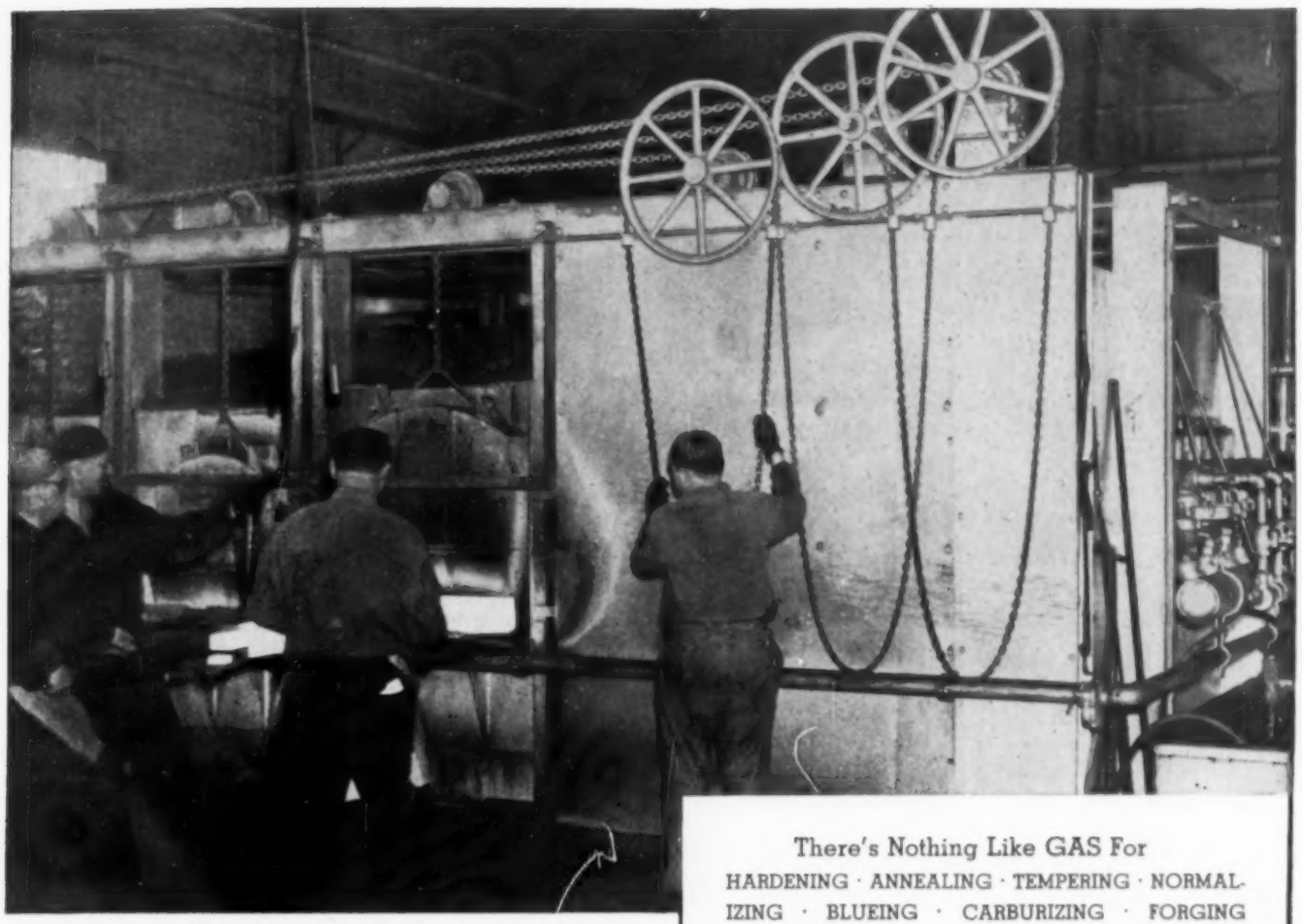

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AUTHORS IN THIS ISSUE

Charles Hardy, whose name is practically synonymous with powder metallurgy and who was one of the pioneers in this comparatively new field, was born in Schleswig-Holstein, studied in Germany, London, and at Columbia University, New York. He estimates that his studies of mining and metallurgical problems have taken him to approximately 40 different countries! In the United States he started the first recovery plant and zinc smelter in Arkansas and operated the first magnetic separation plant for tungsten in New Jersey. He has written much about the minor metals, tungsten, molybdenum and the alkaline earth metals, to say nothing of powder metallurgy.

One who has come up through the ranks is **P. A. Abe,** works manager of the Monarch Machine Tool Co., Sidney, Ohio. Serving first as a machinist apprentice in the plant of the St. Marys Engine Co., he started with Monarch in 1916 as a lathe operator. The intervening 23 years have seen him rise through the various stages of toolmaker, tool room foreman, general foreman, and superintendent, to works manager and to election as a director two years ago. He has charge of engineering, research and production at Monarch.

As efficient in making its results available to the public as in doing the actual research work is the brilliant staff of University of Michigan's Department of Engineering Research, as witness the article describing a spectroscopic laboratory. Of the authors, **Ralph A. Sawyer** has been at University of Michigan since 1919 as instructor in physics, assistant professor, associate professor and full professor. His A.B. came from Dartmouth in 1915 and Ph.D. from University of Chicago in 1919. As a John Simon Guggenheim Memorial Fellow he studied at the Physikalisch-Technische Reichanstatt in Berlin in 1926-27; returned to Germany in 1931 for further study. **H. B. Vincent,** Queen's University, Canada, A.B. 1923, A.M. 1924, won an entrance scholarship, prizes in mathematics and French and a fellowship in mathematics. As instructor in physics at Michigan he gained a Ph.D. and a Sigma Xi key in 1926. After a year as a National Research Fellow at Harvard, he returned to Michigan to the Department of Engineering Research. His title is now research physicist.

While **G. R. Fitterer's** researches have developed the widely used silico-manganese scavenging deoxidizers, the "silicon deoxidation constant", and electrolytic extraction method for non-metallic inclusions, he is perhaps best known for his carbon-silicon carbide thermocouple for liquid metals. His interest in the problems of steel making got its start during his years with the Bureau of Mines in Pittsburgh, where he went in 1927 on a fellowship to work on the "Physical Chemistry of Steel Making" program of the Metallurgical Advisory Board. In 1931 he became head of the metallurgy department of the Bureau of Mines and received his Ph.D. from University of Pittsburgh. In 1934 he left the Bureau to organize the Fitterer Pyrometer Co. of which he is still a director, and in 1935 joined the teaching staff at Pitt.

Charles Hardy

P. A. Abe

Ralph A. Sawyer

H. B. Vincent

G. R. Fitterer

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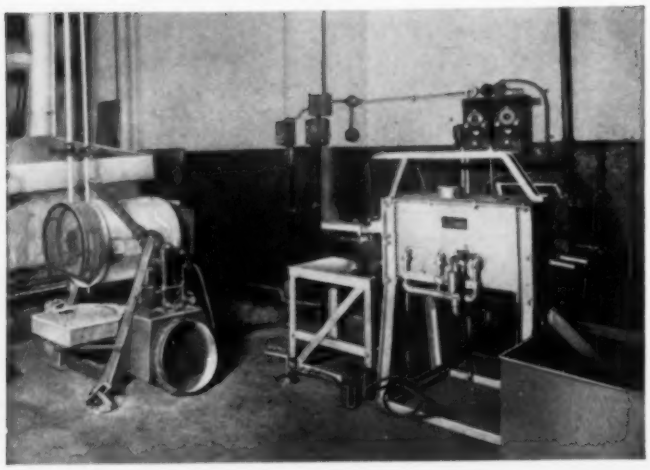

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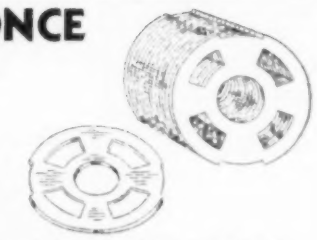

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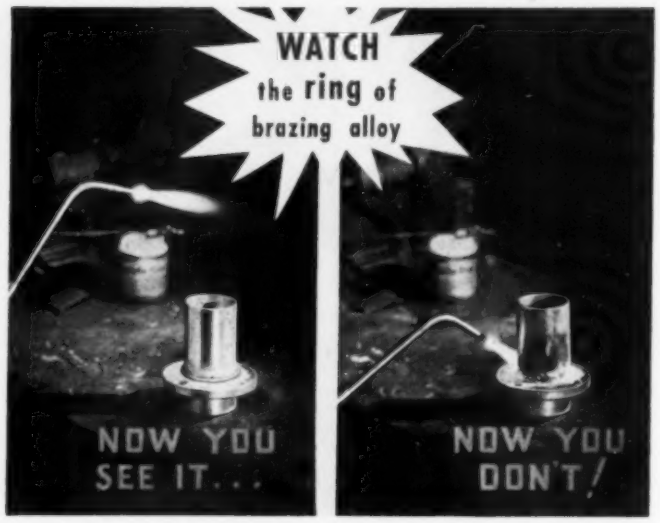

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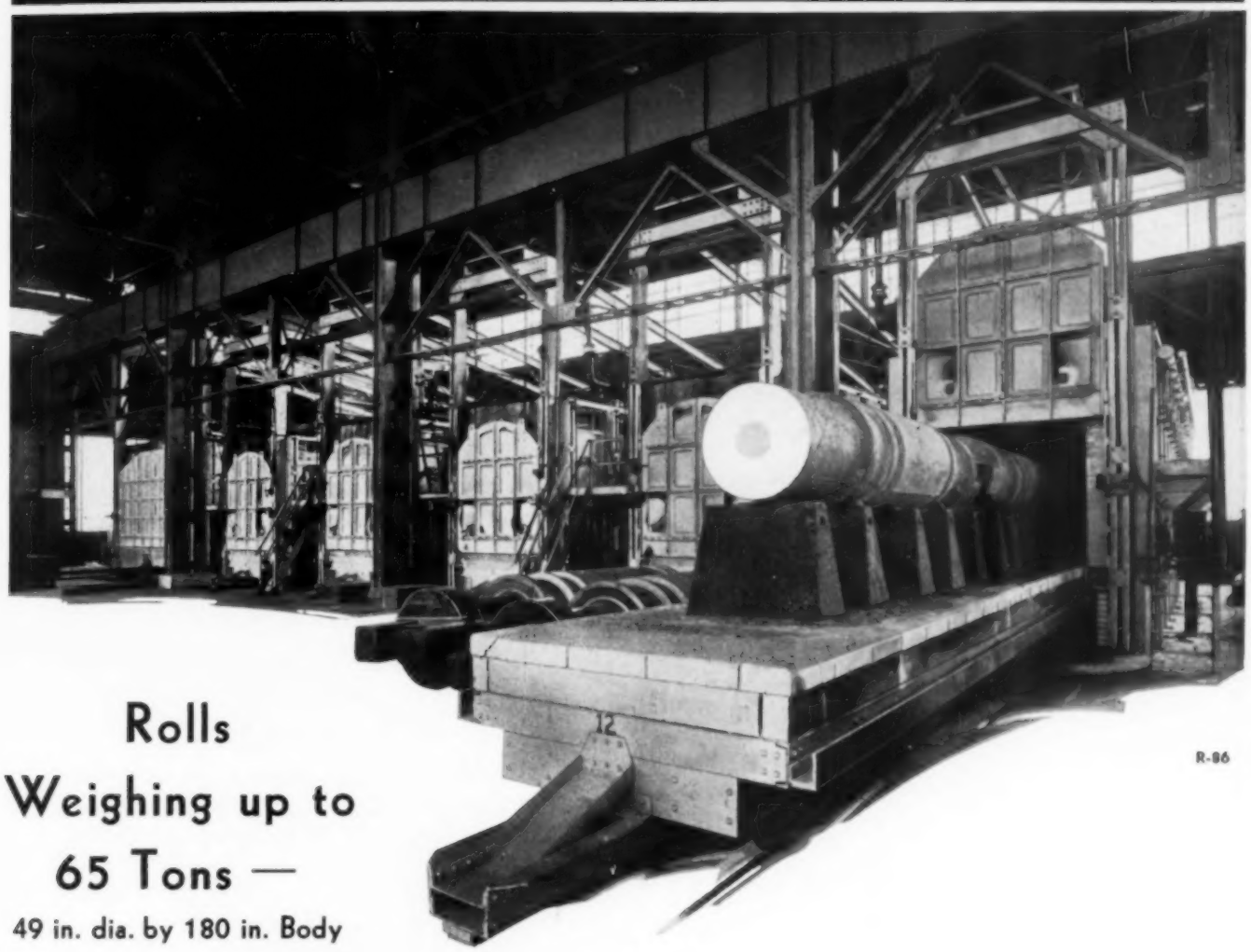

R-86

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B&W Insulating Firebrick have helped to save fuel, reduce annealing time and speed up production. Due to their high insulating value, a very uniform temperature is maintained throughout each furnace.

Bulletin R-2-F gladly sent upon request.

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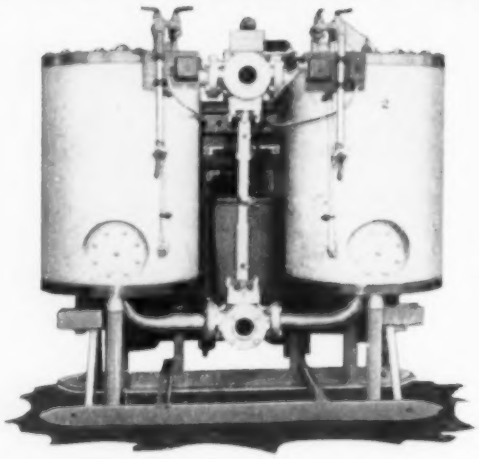

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The books listed below do just that. Look them over and then write for complete details. We'll be glad to tell you more about them.

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Engineering Alloys
Book of Stainless Steels
Physical Testing of Metals
Steel Physical Properties Atlas
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7016 Euclid Avenue
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How Calcium-Silicon raises strength and ductility of Cast Steel

THE use of calcium-silicon with reduced amounts of aluminum instead of aluminum alone for deoxidizing cast steel in the ladle eliminates harmful chain-type, eutectic sulphide inclusions and thus raises the strength and ductility of the steel. The averaged values of a number of tests on .36 to .40 carbon steel showed that this treatment raised yield strength 7.15 per cent, tensile strength 6.49 per cent, elongation 2.52 per cent, and reduction of area 5.82 per cent.

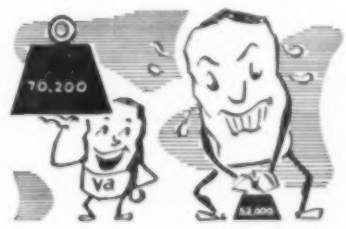
Ask to have one of our metallurgists call and explain more fully how you can improve cast steel with calcium-silicon. He can help make your use of this and other "Electromet" ferro-alloys more profitable, without obligation. Electro Metallurgical Company, Unit of Union Carbide and Carbon Corporation, 30 East 42nd Street, New York, N. Y. In Canada: Electro Metallurgical Company of Canada, Limited, Welland, Ontario.

Harmful chain-type, eutectic sulphide inclusions segregated along grain boundaries in cast steel not treated with calcium-silicon. Magnification—500 diameters.

Inclusions in cast steel treated with calcium-silicon. The inclusions are dispersed and the steel has improved strength and ductility. Magnification —500 diameters. (Both micrographs slightly reduced in reproduction.)

Items of Interest about other "Electromet" Ferro-Alloys

Vanadium Increases Strength and Toughness of Medium-Manganese Steel Castings — The averaged values of a series of tests showed that the addition of 0.10 per cent vanadium to a medium-manganese steel raised the yield point from 52,000 to 70,200 lb. per sq. in., and increased the Izod impact from



20 to 58.7 ft.-lb. Tensile strength, elongation, and reduction of area were also slightly increased.

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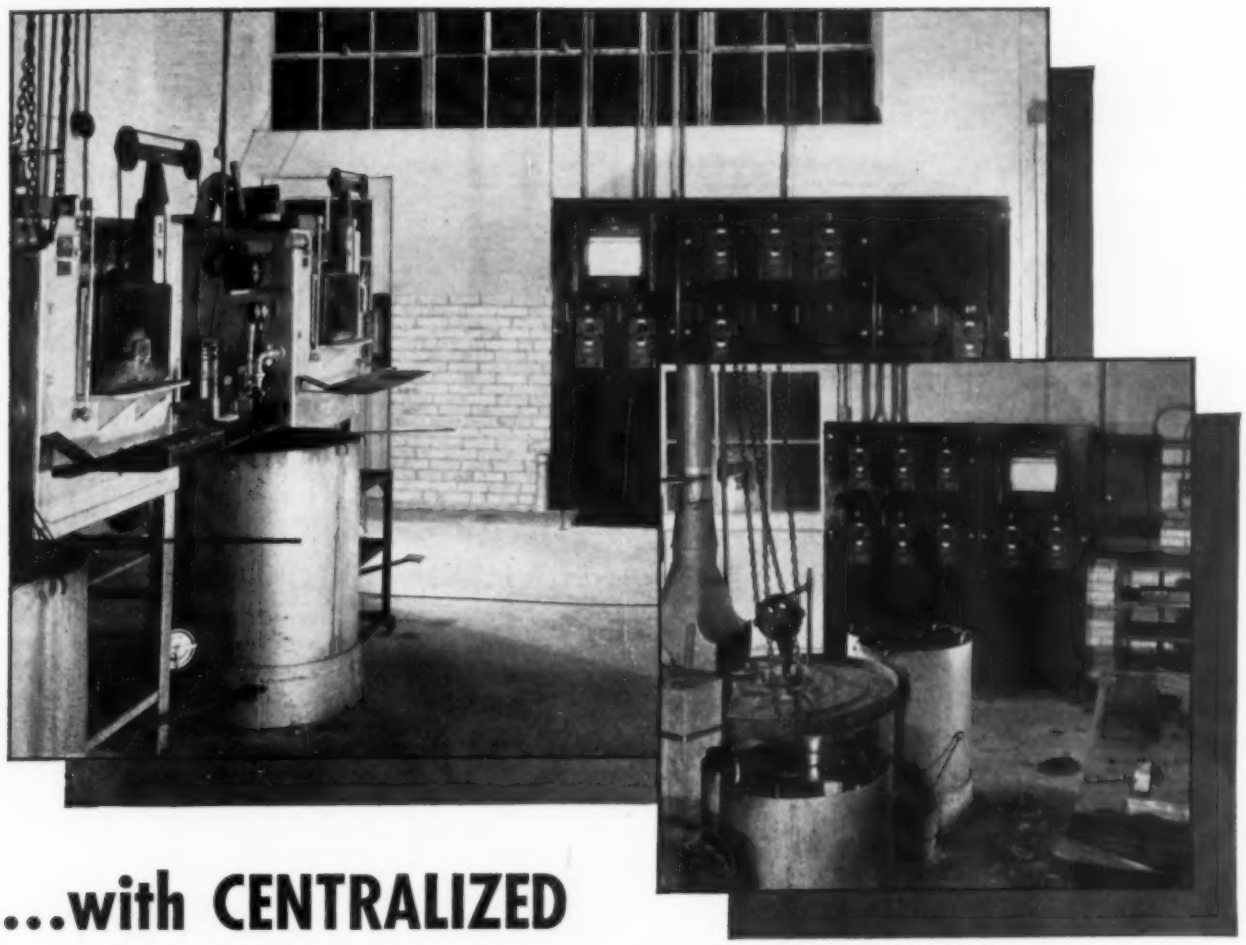

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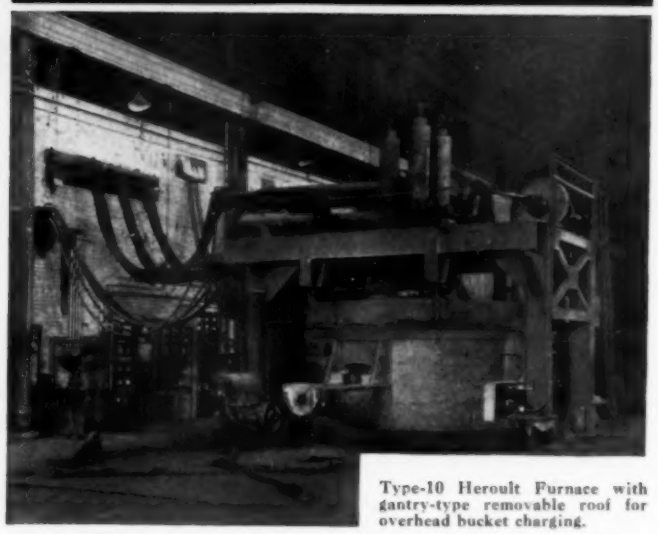

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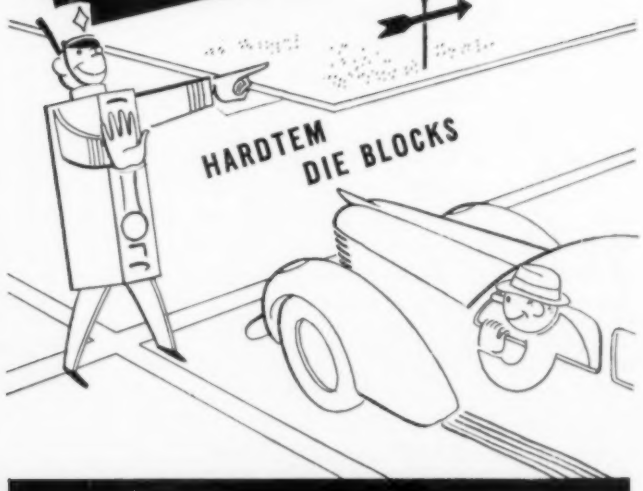

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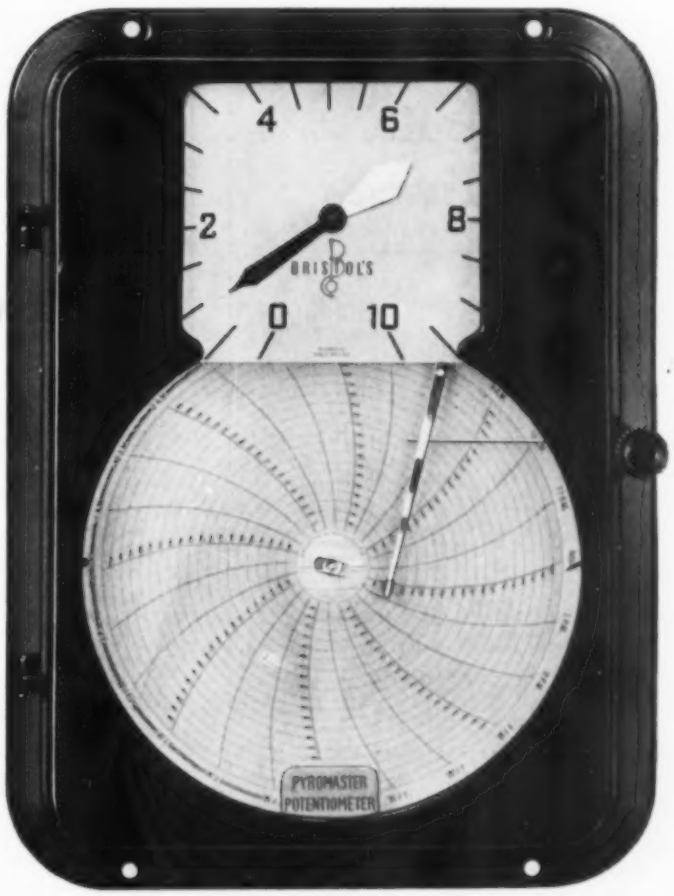

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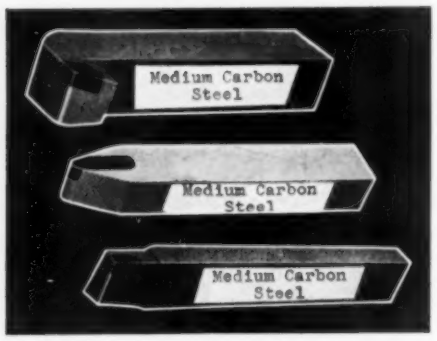

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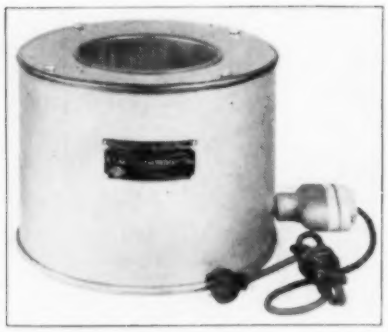

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